THE EVALUATION OF MANAGEMENT INFORMATION SYSTEMS

by

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ABSTRACT

An emerging trend in corporate practices today is that of the development of specialized areas within the company which are devoted to studying its management information systems. Stimulated by the impact of the computer and the subsequent blurring of the distinction between specific systems such as those for marketing, finance, etc., this trend has been accompanied by much academic (and corporate) research in an attempt to provide a scientific approach to the analysis and design of these systems. Several such approaches abound in the literature today, and it would seem that much is still yet to come. The "science" of information systems unfortunately remains scattered throughout the trade and academic journals, papers, and a very few textbooks. This thesis represents an attempt to tie the various areas of research together into a more comprehensive framework, to indicate their validity and limitations, and to relate these areas to practical analysis and evaluation of MIS's.

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PLEASE NOTE: Because of the frequency of its use, the following term has been abbreviated to:

MIS = Management Information System

CHAPTER I

INTRODUCTION

1.1 General Discussion & Definitions

In recent years much thought and many dollars have been spent in the development of new approaches to the problems of management. Virtually all these approaches proceed on the premise that in order to manage, whether this involves organizing, planning, controlling or evaluating, someone must make decisions. Whether facing a certain or uncertain situation, a rational decision-making process requires information; thus every decision maker, whether he be foreman, sargeant, or president will establish for this purpose a supply system for decision making information. It follows that every firm has (or is) an information system. Clearly it also follows that a "better" information system will furnish management with "better" information, facilitating the execution of "better" decisions, which in turn will result in improved performance overall. But what constitutes "better" information systems? The study of information systems has been carried on for some time in the behavioural sciences, the methods and systems groups of many organizations (in particular with respect to the application of electronic data processing equipment), and the area of applied mathematics (providing tools and techniques for management control). Each area has provided a perspective for viewing and understanding

MIS's and the organizational structures and processes which are comprised of these systems, but it is only recently that attempts have been made to integrate these approaches and provide comprehensive and realistic means of analysis. With the rapidly changing technology of today and the evolution of the scientific approach to management, such analysis is becoming more and more mandatory.

One of the most evident facts of life in the past two decades has been the proliferation of available data - the "information explosion" as it has been called. The problem is that data, no matter how abundant, cannot be of use to a decision maker in the absence of a framework and tools appropriate for placing the data in a proper perspective. Data made available for decision making must be gathered, organized and reported in such a manner that it will acquire or maintain a decision making "quality" which permits its (optimum) use in the management decision process. This quality of the data, which will be discussed in the second section of this paper, is usually only achieved at added cost - cost caused by requirements for more accurate basic data and better and faster processing and reporting of the data. Balanced against this cost is the added value of the information to management. However, the problem arises of just how to go about providing tools for analyzing this cost-benefit tradeoff with respect to a given information system. The economic concepts and modelling approaches presented in this paper are offerred as providing the appropriate framework for tackling this problem.

The computer has been a major factor in the information

explosion, and it is to the computer that management will ultimately look for methods of simplifying, organizing and clarifying the major portion of the information to be portrayed to the decision-making function. The most immediate problem here centres around the fact that sophisticated, computerized MIS's evolving today cost a good more than predecessor systems. (See for example articles A-2, A-6 and A-9 in the Bibliography). If a company president studies his system costs, he will soon discover that the equipment and software necessary to support a MIS cost a lot more than the company had to invest in the past in more conventional applications. It is undeniable that there is a higher price tag associated with sophisticated MIS's than the already considerable cost burden that companies have been carrying for data processing technology. As a result, management is taking a closer look at MIS proposals and challenging each new systems project more vigourously.

Associated with the problem of evaluating existing systems is that of new system justification. Even though a proposed system may be very costly, an enlightened company management may be willing to support it if the proponents of the system can demonstrate what the benefits are going to be. In the past, when a computer was installed for repetitive accounting tasks, the cost of the machine and system components was almost invariably justified by demonstrable savings resulting from clerical worker displacement. This approach is no longer appropriate for companies that have <u>already</u> obtained these tangible cost benefits by means of systems presently installed, or who envisage proposed systems as being more than simply routine accoun-

ting machines. Today, the question is not what it may be worth, for instance, to an investment company to update its portfolios and otherwise process the paperwork, but rather what it is worth to provide an investment manager with a display device and the underlying mathematical techniques to aid in the security analysis and portfolio selection. These are benefits that in the past were referred to as "intangible". But most of the benefits of a MIS are of this intangible nature. Clearly, what is needed are new methods of justifying information system costs by quantifying somehow these heretofore "intangible" benefits. Until this is done, it is difficult to see how management can be persuaded to commit substantial company resources to truly effective information systems development.

The "benefit intangibility" problem in information system analysis is thus one of the major difficulties facing attempts to evaluate the effectiveness of MIS's. The other is the difficulty encountered in trying to adequately formalize these systems in order to develop quantitative models and parameters measuring efficiency. While several approaches have been brought forward in hopes of solving these problems, the most promising in terms of quantitative analysis have been matrix theory and decision theory.

Definitions

1. Information: Something which informs us about the state of a certain environment so that the uncertainty associated with such an environment can be expected to be reduced, if not completely eliminated. In information theory it is regarded as a set of potential messages associated

with a given channel or system of information

2. A Decision: The choice of one or more actions between or among feasible alternatives. This may or may not be accomplished according to some set rule, called a <u>decision rule</u>.

3. Uncertainty: The condition or state of a decision-centre who must make a decision with less-than-complete information.

4. The Environment: For purposes of this paper, this will refer to events, entities and data in the past, present and future which are relevant to the decision but not under the control of the decision-maker.

5. An Event: A subset of the <u>states</u> of the environment.

6. Data: Unprocessed facts relating to some object or event which may or may not relate to the decision.

7. An Outcome or Result: Something which happens as a consequence of an action and the <u>true</u> state of the environment.

8. Data Base: A collection of data relating both to the firm's environment and to its internal operation, which is classified by functional area of operation (see Figure 4, Chapter 5) into "modules", each of which then contains a set of data which is sufficient to satisfy management's informational needs from that area. These modules may be deleted or added to the system as the nature of the firm's business or its environment changes.

9. An Information System: The total of all sources, processors, and users of information in the firm. Thus, an <u>information</u> system is arbitrarily regarded as identical to a <u>decision</u> system (whether or not these are conceptually

different is considered beyond the scope of this thesis), and both formal (paperwork) and informal, manual and automated systems are included.

10. Modular, Data-Based Information System: A sophisticated, computerized information system which produces information and reports for decision-making by "polling" the data base modules and processing the data through a control centre normally referred to as the central processor.

1.2 The Decision-Making Framework

Every student of business should be aware that the decision process has been well documented and is considered to consist of four steps:

(i) Identify the problem, decision environment and goals.

(ii) Formulate all possible alternative solutions (actions).

(iii) Analyze the consequences of each alternative in light of the appropriate goals and the decision environment. Conceptually, this entails:

(a) Assessing the result which each action-event pair will yield.

(b) Assigning a utility value to each of these results.

(c) Assigning a probability to each event.

(d) Determining the resulting "expected utility" of each action-state pair.

(iv) Choose the most favourable alternative. Decision Theory would dictate that this means choosing the action (solution) which yields the highest expected utility (neglecting risk).

There are, of course, many difficulties involved in carrying out these decision rules in practice. Any given result will usually have many implications, the quantification of which in equivalent or comparable measures may be impossible. This is the inherent difficulty in assigning utility values, the essence of the above procedure. In addition, many would feel that the essential part of the process ended with the third step, and that the fourth was either a simple consequence of the previous analysis or an arbitrary judgement among equivalent alternatives. Indeed, this is often the attitude of information theorists - that any decision-making process is primarily an information-analyzing process and that the emphasis should be on the collection, interpretation and evaluation of the available information, not on any "decision" or "strategy" criteria. These theorists typically ignore the existence of uncertainty (unavailability and inaccuracy) of information, or assume it away.

But where does the information come from that management uses in selecting among alternatives and making these decisions? What additional information would management like to have regarding the alternatives? Is this information available, and if so, is it economically feasible to process and report it? Should there exist a screening device so that only exceptional information or information with a specifically high amount of "value" is transmitted to management? What represents an "optimum" decision-information system in a given situation, and how close can we approach the theoretical ideal?

It is precisely in answer to questions such as these, and

many others like them, that the information-decision theorists have emerged as important in management study, and a complete, though as yet disorganized approach to the analysis of business information systems has evolved. Recent trends towards large EDP installations have further stimulated the development of such an approach, and in particular the establishment of comprehensive criteria to assess the performance capabilities of modern information systems.

An information system is a service facility to the management of an organization (and yet they themselves are part of these systems) in that decisions are made on the basis of information which is supplied by the system. Such a system has certain elements that are essential, regardless of the environment:[1]

1. Decision Centres - a place in an organization where a decision or part of a decision is made. This may be an individual, a group, or a machine.
2. Information Centres - a place in an organization where information is collected, transmitted, stored or analyzed. The information may be about the external environment (e.g. competitors' sales) or about the internal operations (e.g. production data). The information need not be data; it may be the promulgation of a decision; it may involve human relations factors; etc.
3. Information Links - these determine the flows of information among information systems and between

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1. Bonini, C.P., Simulation of Information & Decision Systems in the Firm, Prentice-Hall, 1963

information and decision centres. In general in a business organization, this is a complicated network.

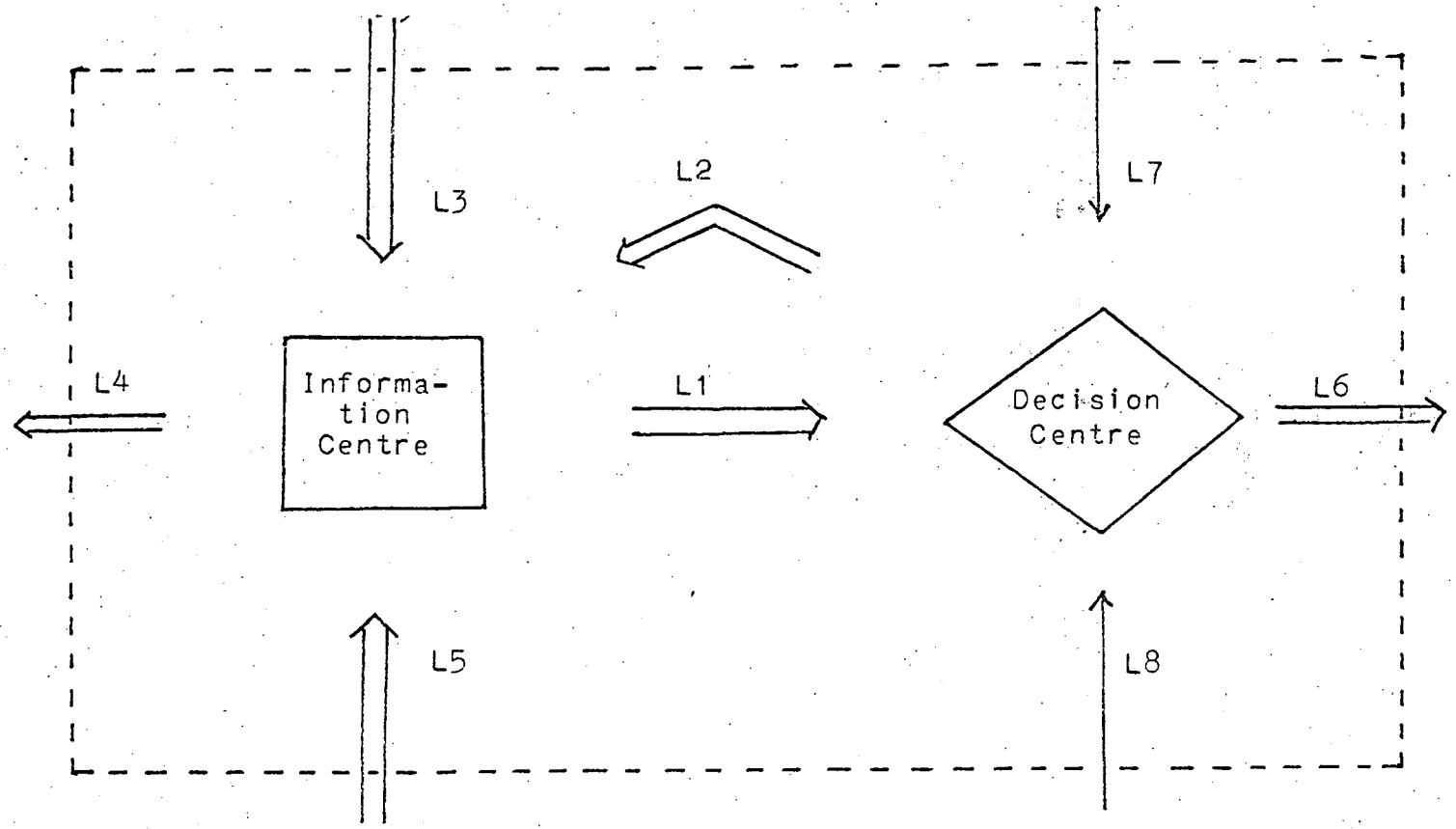
The information system (which itself is part of the total corporate decision system) is the complete set of linkings of information within the organization. A typical information-decision "module" within a network might be represented as given in Figure 1.

The information system approach is a special method for viewing and analyzing a business organization or any segment of a business organization in such a way that the business process is conceived as a logical structure composed of information centers, information links, and decision centres. These basic components must be arranged in such a way as to efficiently promote information flows throughout the system. Information flows themselves represent the results of relating or matching the requirements for information with the sources of data for each decision. This matching process is accomplished by management, and frequently involves the employment of various management science tools and techniques. The role of the information - decision system is portrayed in Figure 2.

1.3 Purpose and Scope of the Thesis

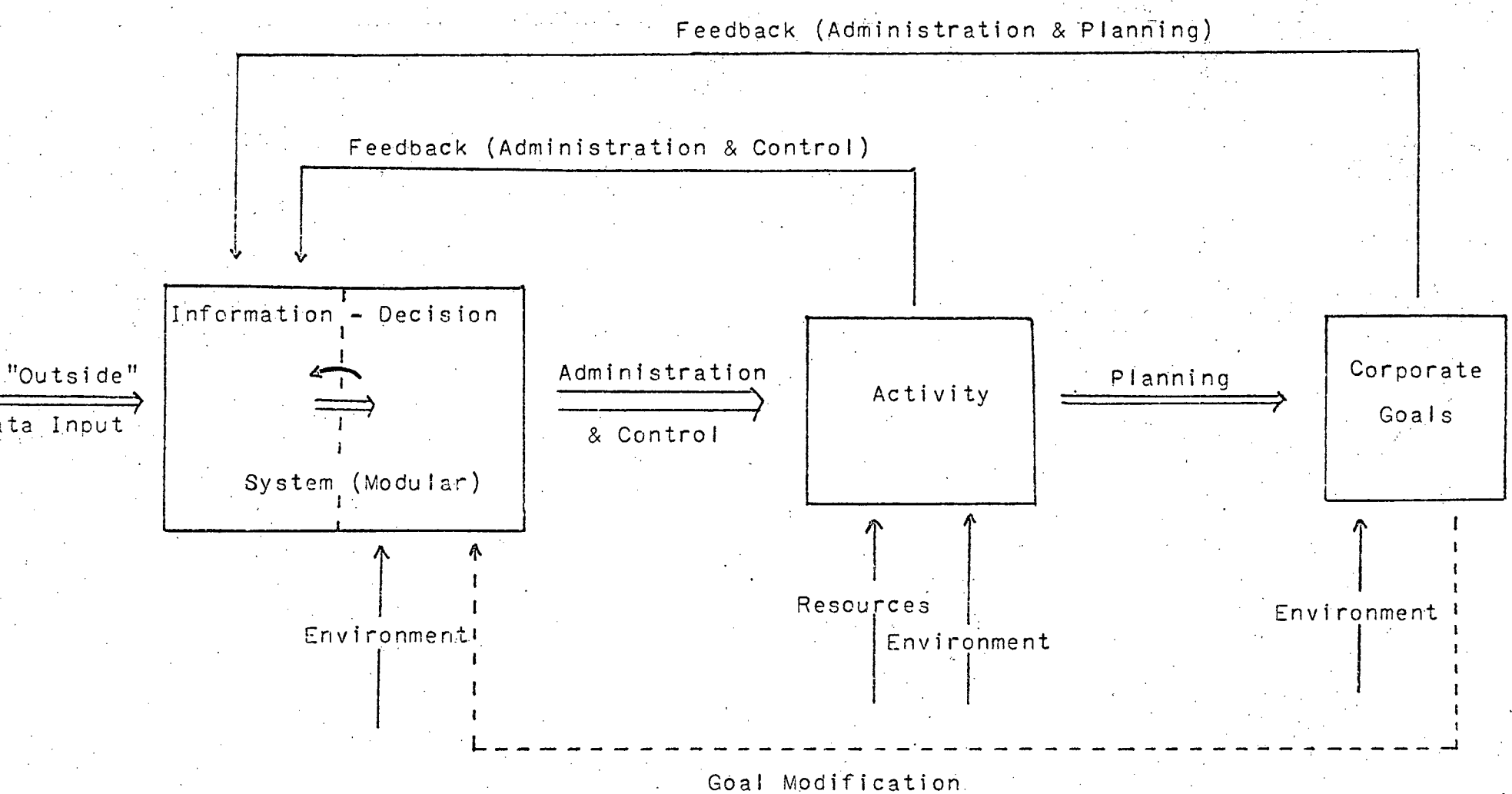
In general terms, it will be the purpose of this thesis to propose the basic components of an "Information System Science", that is, to bring together several disjointed areas of research on the subject in the hopes of laying the proper economic and mathematical format for the development of such a

Figure 1 A TYPICAL INFORMATION-SYSTEM MODULE



Legend:
L1 = Main Communication Link, Internal
L2 = Feedback Link, Internal
L3 - L6 = Formal Links with Other Modules
L7 & L8 = Informal Links with Other Modules

Figure 2 INFORMATION PATTERNS IN THE FIRM



"science", in particular as it relates to evaluation of such systems. Specifically, the purpose will be threefold:

(1) To examine the current body of literature extant in the field of MIS evaluation; to tie the various areas together in a logical framework; and to point out the "directions" in which the most fruitful theories are attacking the problem of MIS evaluation.

(2) To evaluate the validity, limitations, and practicality of the theory and indicate where possible the implications of the theory on the analysis of practical, operational MIS's.

(3) To delineate areas for further research and refinement in information system theory and practical MIS design.

The scope of the paper will be delineated by defining the subject matter and the approach. In proposing a framework for evaluating MIS's, the subject matter will present the economic concepts and mathematical techniques for aiding such evaluations, where a MIS has been defined previously. While this paper will examine primarily formal (paperwork) systems, the effects of informal communication will also be recognized, and although the orientation will be towards the evaluation of existing systems, the relevance of the discussion to the problem of design and analysis of new or proposed systems will be realized. As a basis for establishing the framework for MIS evaluation, the quality and economic aspects of information itself will be discussed.

The problem of MIS evaluation will be approached as a value-cost tradeoff, and this paper will attempt to tackle the

issue by offering answers to the following question sequence:

(1) What are the relevant aspects of value in information itself, and what are the determinants of information cost? (Chapter 2).

(2) To what degree can MIS's be described and to what extent are they quantifiable in mathematical models? (Chapter 3)

(3) Given the aspects of value and cost of information, and given the most appropriate (and realistic) model of a MIS, can we derive parameters and techniques for the evaluation of the value-cost tradeoff of an information system itself? (Chapter 4)

An attempt will be made to remain as oriented as possible to the most fundamental aspects of the existing theory, and to adhere to areas of the greatest practical implication.

CHAPTER 2

THE EVALUATION OF INFORMATION

2.1 The Nature of Information for Decision-Making

Since information is the output of an information system, in order to determine the value associated with such a system, we must ascertain the value of this information. Similarly, the cost components of an information system will be determined, at least in part, by the basic cost elements of information. Thus, it seems in order to start with the evaluation of a given system by analyzing the value and the cost of the information it produces.

Since data becomes information when significance is derived from it by management, an information system can be regarded as a system of channels designed to handle the data input, process it, and produce information as efficiently as possible. However, decision-making information is not homogeneous and different kinds of information must be treated differently. Similarly, information has several characteristics which give it quality, usually at added cost. In order to design or evaluate an information system, it is necessary to describe both the kinds of information it is to handle, and the characteristics which the system will be expected to add, amplify or retain in input data in order to transform it into information with a

specifically high quality at lowest cost. Following is an attempt to delineate the various classifications of corporate information, to define what is meant by decision-making information in this context, and to categorize the characteristics of information which give it quality or value, and add to its cost.

Basically we may classify five general classifications of "business"information. For a more detailed discussion of these, see Dearden, listed as C-2 in the Bibliography, but in brief these are:

1) Formal vs. Informal Information: formal information being documentary data expressed in some kind of permanent form and which is transmitted through the formal information channels of the firm. Informal information is non-documentary and may be transmitted by word of mouth, personal observation, etc. Informal information does not follow the formal channels.

2) Status vs. Operating Information: Status information is non-recurring, at least in the short run, is not normally a part of the control process, and is most commonly generated through special studies. Operating information is recurring information which is generated at regular intervals for purposes of control and evaluation.

3) Action vs. Non-Action Information: Action information is that which, with varying degrees of urgency, requires the decision centre to take some action or make a yes-no decision on taking some action. The term "non-action" information then is self-explanatory, but this can be divided into several categories; for example, information giving notification that some action has taken place, or information which is being compiled

to eventually become part of an action report.

4) Internal vs. External Information: This distinction is provided by the source which generates the information, i.e., whether it is generated from operations of the firm, or from its external environment.

5) Historical vs. Future Information: This distinction is based on the time period covered by the information.

MIS's cannot be designed or evaluated on the basis of efficient handling of all these classifications of information. Informal information, often extremely important for business success, is by its nature not amenable to prediction or description in formal analysis. Furthermore, generally speaking an efficient MIS is one which will minimize the generation and processing of non-action information, and status information may often be generated outside the formal channels. Thus an MIS must justify itself on the basis of the efficiency with which it permits and promotes the reporting of two basic classifications of business information:

(i) Operating information, usually historical, which is useful for making action decisions with respect to internal operations of the firm. It is this kind of decision-making information upon which efficient lower and middle management depends.

(ii) External information which reflects as much as possible future conditions and which also promotes action decisions. This kind of information is crucial for upper management in making long-range decisions.

For purposes of clarity, we can define these latter kinds of information as decision-making information, and it will be to

this kind of information that the characteristics and discussion to follow will refer.

Information of this kind can be described in various ways. For the purpose of evaluation, however, the characteristics of decision-making information which are of interest are the components of cost and value. Although value and cost of information are not both functions of all the characteristics, and certainly not similar functions, a complete listing of the relevant characteristics will facilitate the analysis to follow. These characteristics are, then:

(i) Quantity: This is simply the amount of information generated, processed, and reported. Presumably, the greater the quantity of information, the more variables the information describes, and the more comprehensive a report will be. However, more information is not necessarily better information and this is amply illustrated by the fact that a high speed printer today can print more data in a single hour than a manager can reasonably digest in a month.

(ii) Accuracy: In the sense of precision, this means gathering all input data with seven significant digits instead of four. However, precision may be spurious and tied to some unrealistic convention of the past or some book-keeping rule. Cost data accurate to the nearest penny cannot be combined with sales forecasts in rounded thousands to give profit estimates to the nearest penny. This concept of accuracy includes those of correctness and dependability, which reflect the information system's ability to avoid errors and inaccuracies and consistently report exact information. These are functions of the "noise"

inherent in the system (often directly related to the human content of the system) and the degree to which checks and verifications, as well as feedback, have been built into the information system.

(iii) Timeliness: This is a complex function of the interval, or time period between reports, the reporting period over which the information is gathered, and the delay, or waiting time until it becomes available. Information clearly suffers a loss in value as delays increase and/or the interval is too long. However, information also clearly accumulates greater cost as these restrictions are tightened. But where is the trade-off?

(iv) Format: The form or method of presentation. Much time can be spent hunting for information in a report full of facts; thus information must be tailored to the needs of management if it is to be useful. A common phenomenon is that reports become smaller and more concise as they are filtered upwards through the managerial hierarchy.

(v) Relevance: Information is valueless unless it can be used as an aid in decision-making; thus, the relevance or applicability of the information to the decisions at hand is a major criterion. This is also the most nebulous of the concepts since as a decision centre, a manager's effectiveness depends on how he arranges for messages to flow to him and how he filters out the more significant content of the messages received. The manager (decision-centre) at each level is the only instrument that can provide either formal or informal measures of information values. Others can influence the factors that go into a given manager's measures, but these measures (value judgements)

can operate only in his mind. This poses a significant problem to any information-value approach to management systems.

For a further discussion of these characteristics of information and the degree to which they relate to value and cost, the reader is referred to the rather opposing views presented in items C-4 and C-5 in the Bibliography.

2.2 Aspects of Value - The Value Function

Data cannot become information until it acquires decision-making value, related to the amount and efficiency with which it reduces the uncertainty facing the decision maker. Information must therefore have a value function which describes the value dependence of the above characteristics of information. It is postulated here that the characteristics listed previously represent these components of value, and the degree and manner with which they do so will be examined.

(i) Quantity: Perhaps the simplest to describe in economic terms, the amount of information supplied will almost invariably assume a point of diminishing returns. Up to a certain point, we can expect to see value rise from zero to a peak, beyond which additional information (assuming the same degree of accuracy, timeliness and relevancy) only lessens the decision-making ability of the user, and adds less value than previous amounts. This concept, while economically and psychologically sound, is very difficult to deal with in practice, since it is closely tied to the ability and capacities of the individual decision-maker. In addition, it is the opinion of several authors, including Ackoff,[2] that present day managers indeed do not

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2. Ackoff, R.L., "Management Misinformation Systems", Management Science, Vol. 14, No. 4, December, 1967, p. B-147

suffer from a lack of relevant information; rather, it is more common that they are besieged with too much information, thus operating past the point of diminishing returns and experiencing a kind of "input overload". This phenomenon suggests that two of the most important functions of a MIS must be condensation and filtration (implying pre-evaluation of input information to the decision centre).

(ii) Accuracy: Again accuracy, as defined earlier, will also exhibit the law of diminishing returns, though this depends directly on the user and the situation. More accuracy is warranted if a larger margin of accuracy might cause the manager to make a different decision. Value is lower when the margin of accuracy is low (ceteris paribus), and the value increases rapidly as the margin is increased, up to a point where it may have little or no bearing on the outcome. Although only rarely will further increases in accuracy actually impede sound decision-making, the cost associated with this accuracy margin will be prohibitive.

(iii) Timeliness: The quality of management decisions is related to when they are made. Timeliness of reported information can perhaps best be described in terms of intervals, periods and delays as defined earlier. The "reporting delay" may be thought of as composed of two elements: an inherent age of the data, and a processing delay. Operating information covers a period of time during which events have happened. Therefore, the age of operating information depends on the length of the operating period, since some events happen early in the period, some near the middle, and some near the end. Information about

operations throughout a period of time, then, has an inherent average age of one-half a period, merely because the events involved are spread throughout this reporting period. The processing delay involved in producing the reports must be added to this inherent time lag of one-half a period to give the minimum age of information before it is available for use. Status information, by definition historical, has no inherent age; thus its minimum total age is dependent only on the processing delay.

It is also possible to decrease the age factor, thus increasing information value, by a reduction in the reporting interval. Thus one can have the same information but at a faster rate. However, there are limits to the shortening of the reporting interval as too great a frequency can lead to erratic information in the short run and thus render it useless for forecasting purposes. Also the reduced interval means more reports to read, file and prepare, thus encountering the "quantity" problem discussed above. The optimum interval for each reporting process will vary with business conditions and different kinds of reports, so that the complexity of the supporting system will tend to outweigh the value advantages.

The usefulness to management of any information can be related to the reporting period directly. Here again, a marginal concept is used in that as the period progresses, the value of information declines, with the greatest usefulness occurring in the first half of the period. Any increased total delay will then decrease this peak usefulness and any reduced total delay will increase its usefulness for decision-making.

The optimum age of information is then a blend of the fac-

tors of internal reporting interval and processing delay. However, there is no clearcut relation between the frequency of reporting, reporting period, and value. For example, the fire alarm is a signal response with no delay and no regard for the last interval between alarm signals. This lack of relation then leads to the use of "real-time", "on-line" systems for information processing such as that used for national defence.

(iv) Format: Here the classical marginal return approach breaks down, for many dollars and much effort can be devoted to form and structure design of information system output, while a little imagination and fore-thought may yield the best design with a minimum of effort. For this reason, this is the element of value most readily accessible and most often used in systems analysis. In addition, there may be no optimum format, only some which are more aesthetically pleasing to some decision-makers than others. Thus, psychological aspects(the theory of perception) becomes relevant, and once again we have the utility or value structure of the decision centre imposing a good deal of individuality on the merit or value measure of output information. Also, while the benefits of improved format design are more tangible than some of the other characteristics, the problem of individuality and the fact that it is difficult to conceive of a continuous value function for it, makes the application of traditional economic analysis difficult.

(v) Relevancy: While some information will be obviously relevant to the decision at hand and other information will not be, there may be many grey areas. Unfortunately, information can be partially relevant, and parts of the information provi-

ded can be relevant, but the reduction in uncertainty of partially relevant information for one individual may be considerably different than that for another. If decision-makers A and B both wish to judge the success of a plant or subsidiary, and each requests the relevant profit-volume-cost figures, giving A only volume may satisfy him for purposes of the decision he must make (i.e. - part of the relevant information), while B may be satisfied with a comparative variance analysis report (partially relevant information). Attempts to determine the requirements for information within an organization are often initiated on the presumption of "asking management what it needs". In practice, the manager rarely can explicitly define his informational requirements in total, yet he consistently makes correct decisions within the information he does have or eventually gets. It is this intuitive or instinctive aspect of many decision centres that plagues the analyst, and it is this uncertainty about the decision maker's utility structure that renders much of the theory on the evaluation of MIS's totally impractical.

To summarize these value characteristics then, we have postulated a value function for information of the form:

$$V = f(Q, A, T, F, R) \text{ where } \begin{cases} Q = \text{quality} \\ A = \text{accuracy} \\ T = \text{timeliness} \\ F = \text{format} \\ R = \text{relevance} \end{cases}$$

For the first three independent variables, the function will exhibit the diminishing returns principle, and thus will assume the familiar "hump" shape, while for the remaining two, the form of the function is more dubious. If format and relevance are given or assumed to be of no importance on a given

instance, then the value function for information might appear similar to that of Figure 3.

2.3 Aspects of Cost - The Cost Function

It should be noted at the outset that associated with information are two basic notions of cost - a communication cost and a risk cost. Communication cost naturally is the cost of procuring, processing, and reporting information. Risk cost, however, is basically a decision cost. It relates to the uncertainty present in the decision-making process as a result of the absence or lack of quality of the information, and is directly associated with the probability of making a wrong or less-than-optimal decision. Unfortunately, this kind of cost is difficult to measure, and a decrease in the risk cost usually can only be obtained at the expense of increasing communication cost. Thus total cost must be a balance between these two for an optimum condition.

(i) Quantity: While the cost associated with more information may be simply linear, the cost function will depend a great deal on system capacity. The capacity of a system must be large enough to handle peak loads, and the fixed costs of a system - personnel, equipment, space, programming, etc. - are determined chiefly by the maximum capacity of the system. Operating costs - media, overtime, and others - are sensitive to volume. When the peak load is much greater than the average processing load, either more capacity must be provided to handle the peak, or the elapsed time required for processing will grow. Such extra capacity may then be idle until the next peak occurs.

Thus, due to the existence of fixed system capacities and therefore some optimum (minimum cost) operating point, the cost function for quantity is more likely to be U-shaped than linear.

(ii) Accuracy: While precision is an important component of cost, the major cost determinant here will be reliability. Reliability implies a system of built-in checks from data gathering, through data processing (via validity and parity checking hardware) to data recording. The more the standard deviation of reported results around the true value is reduced, the greater will be the operating costs of the system. This relationship is usually found to be exponential.[3]

(iii) Timeliness: Just as for the value function, the cost function for the timeliness of information is dependent on the factors of interval and delay. Again, for a more detailed discussion, see Gregory & Van Horn, item C-5 in the Bibliography, but in brief the cost implications are discussed here.

It is often observed that the relationship between the cost of processing data and the length of the interval between preparation of successive reports is non-linear; that is, reducing the reporting interval will usually have a more than proportional effect on costs. This is true since the cost of summarizing files and preparing reports is related to the number of reports prepared, it often being found that costs double each time the reporting interval is cut in half.[4] As the interval approaches zero, of course, we approach the continuous-monito-

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3. Gregory & Van Horn, Automatic Data Processing Systems, Wadsworth Publishing Company, Belmont, Calif., 1962, p. 349

4. ibid. p. 350

toring case of the "on-line" system, in which data is being continually fed (or is continually available) to the decision-centre, such as is the case in the process control systems of many large oil refineries now in operation. These systems are also the most costly.

In addition, shortening the processing delay for a given system will normally increase costs. For any particular system using certain methods - manual, electromechanical, or electronic - there will be some processing delay which has the lowest operating costs. Human and equipment components are used at a high fraction of capacity and neither overload nor idleness occurs. Again, as the delay is decreased towards zero, we approach the real-time, on-line system which will normally entail the greatest cost.

Again, the familiar U-shaped curve would probably describe the cost function best, with an implied minimum at a particular age-interval combination and increasing costs where the search for and reporting of information becomes extreme.

(iv) Format: Again as was the case earlier, it is difficult to conceive of a definite cost relationship for this variable. This is due in part to the fact that the costs associated with poor or less-than-best formats are largely of the risk cost variety, rather than of measurable communication cost. If a decision-maker mis-reads, omits or simply cannot understand information portrayed in a certain way, then the probability of his making a poor decision is greatly increased and the cost associated with such a decision error may far outweigh the communication cost of reporting the information in any format.

Thus, it is easy to justify putting many dollars into improving this area, since the cost associated with failure to produce information in good formats, though unmeasurable, is implicitly high.

(v) Relevance: Here again a cost function is difficult to postulate, since the cost associated with gathering, processing and reporting relevant information may be no more, in terms of communication cost, than that for information which is irrelevant or less-than-optimal. Again the risk cost is the major factor, the possibility of erroneous decisions increasing as relevance (admittedly subjective) is decreased.

To summarize once more, the cost function has been assumed a function of the five characteristics, in differing ways; i.e. -

$$c = f(Q, A, T, F, R)$$

where the relationship will assume a U-shape for the first three independent variables while the relationship for the last two is unknown. Again, if the format and relevance problems are considered overcome, the cost function might appear as given in Figure 3.

2.4 Guidelines for the Evaluation of Information

Given these two functions of cost and value, one can arrive at the theoretical optimum operating point by simply choosing that combination of input characteristics which yields a maximum for value minus cost. This might appear as indicated in Figure 3. This optimum, then, represents a "best" quality mix; that is, the best possible combined alloca-

tion of effort into each of the characteristics of information quality.

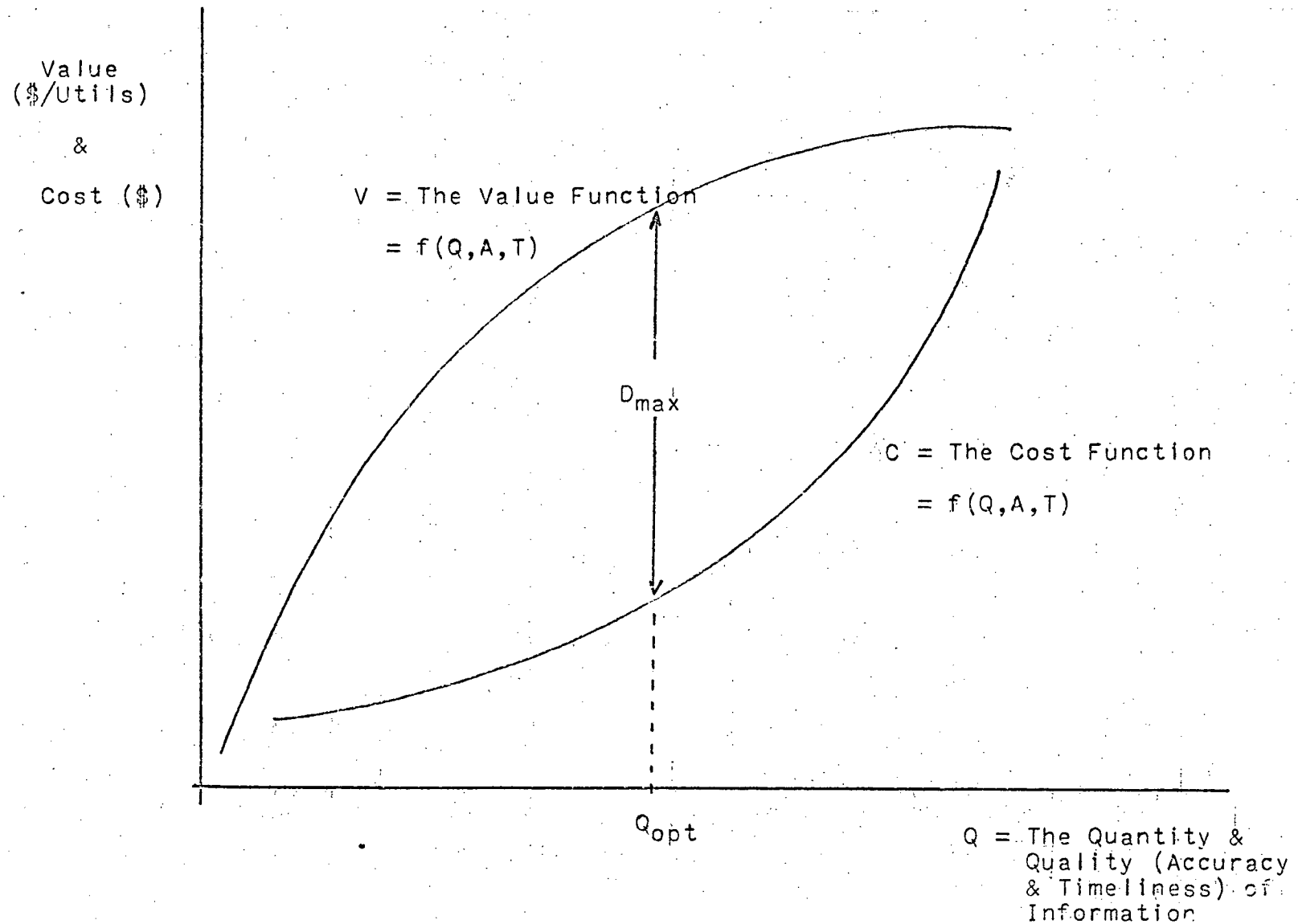
It will be noticed that the value measure for input characteristics is somewhat dubious, being measured both in dollars and utils (where a util represents some unit of utility). This is again an indication of the difficulty involved in ascribing to output information a quantitative value measure. The traditional approach of economics is to pursue the theory that profit maximization is the primary objective of the firm. From this standpoint, it follows that additional information has value according to the difference in profit that would accrue to the organization with and without the availability of such information. However, the characteristics of information make such a simplified approach untenable. First, capital and labour usually yield measurable gains when incremental amounts are added to the production process. Information, however, does not behave as an independent variable. Its value and cost are multi-dimensional functions of the five characteristics discussed previously. Thus, the additions to decision effectiveness or uncertainty reductions are not simple functions of the amount of information supplied, but also of the quality of information inherent in the presence or absence of the characteristics, making incremental analysis on additional units of information difficult.

Secondly, information is inextricably tied to notions of uncertainty reduction and decision-making effectiveness, both probabilistic concepts, making the value of additional units of information or information quality difficult to measure in objective units. For example, a single unit of capital input

will add Q units to output over some range, but information "bit" B may reduce the uncertainty associated with manager X's decision task by a considerably different amount than it reduces manager Y's decision uncertainty, due to their different decision tasks and differing utility measures.

For these reasons, the approaches of traditional economics which argue that information, similar to other inputs to a business organization, should be treated with the theoretical technique of marginal analysis (that is, information should be acquired until that point of operation is encountered where marginal cost equals marginal revenue), are somewhat inadequate. What seems needed for information evaluation is a "decision-oriented" approach which permits the analysis of output information directly in terms of the nature of the decision task, the way in which the provided information is used in the decision process, and the decision-maker's utility structure. Such a method must then yield efficiency criteria for information which measure the degree to which it reduces decision uncertainty. Such an approach is that of decision theory, and it will be the purpose of the next section to illustrate the applicability of such an approach, and to compare it with a matrix formalization of the MIS structure.

Figure 3 THE EVALUATION OF INFORMATION



CHAPTER 3

MODELS FOR ANALYZING MIS'S

3.1 The Problems of Formalization

The information system of the business firm represents the mechanism by which it functions. The efficiency with which information flows among the firm's decision centres reflects not only the ease with which decisions can be made, but also the overall degree to which the organizational structure of the firm meets the needs placed on it by its purpose. Also, decisions imply authority, and the formal organization of the firm is based, to a large extent, on authority relations. These decisions must be based on information. Thus the information system of a firm corresponds closely to the organizational system, i.e. - the formal organizational structure shoudl be predicated at least in part by information-flow requirements. For these reasons, the formalization (i.e. - the representation in some kind of quantitative or other "formal" form) of information systems is extremely valuable and lends considerable insight into the problems of management. Thus the modelling of these systems, particularly insofar as it yields effectiveness criteria, is singularly useful. In addition, actual MIS's generally exhibit the following characteristics:

(i) They represent the organization of the decision (activity) centres of the firm; thus, a significant portion of its

total resources. MIS's are thus usually quite costly.

(ii) MIS's tend to be strongly differentiated, often to the point of being one of a kind.

(iii) Since erroneous decisions can result, design errors in MIS's are very costly.

(iv) In accordance with (i) above, the trial-and-error testing of alternative MIS's is very expensive if not impossible.

Thus, actual experimentation with MIS's is usually costly and often impossible. The result one encounters in practice is that the MIS of a firm is developed, as the firm develops, around its organizational structure. In this process, marketing, financial, production and distribution information systems evolve over time to meet the needs of the corporation and the personnel who carry out its decision-making activities. However, this kind of an evolution often results in inefficiencies such as redundancies, repetitions and mis-use of gathered data. The modelling approach to the evaluation and design of MIS's is a method for envisaging the total MIS of the firm, describing it quantitatively and thus attempting to either delineate (in the case of evaluation) or avoid (in the case of design) the aforementioned MIS inefficiencies.

As mentioned previously, there are two central problems which make quantitative analysis of information systems difficult:

(i) The fact that information itself is an elusive concept in the business context and is difficult to deal with using traditional approaches.

(ii) The fact that systems of information in the business context are difficult to define, difficult to restrict and difficult to formulate analytically.

In addition, there is the problem of formulating efficiency criteria on a common basis. That is, there is a problem in deciding whether the model will derive cost effectiveness parameters or value effectiveness parameters. Cost effectiveness parameters measure the efficiency with which an information system procures, processes and displays information, given information inputs and outputs. The cost-effectiveness approach is the one normally adopted by accountants and systems groups who are given the task of streamlining the processing of data or costing the system by information centre. Value effectiveness parameters measure the effectiveness with which the output of an information system reflects changes in the firm's environment. This approach is much more theoretical and deals with the application of probability, statistics and related theories which attempt to formalize the decision-making situation. The problem confronting present day information theorists is that of deriving a modelling approach which will incorporate both cost effectiveness and value effectiveness considerations.

Following in this chapter are two models which highlight both the most recent approaches to solving this representation problem and the problems (found implicit in the assumptions of these models) which confront the modelling approach. The first is basically a cost effectiveness model dealing with given inputs and outputs of information availability and requirements.

The second is basically a value effectiveness approach dealing only with the decision-making effectiveness of the information provided by a certain given information system structure.

3.2 A Simple Matrix Model

3.2.1 Formulation

Possibly the first analytical model for this purpose was that proposed by Lieberman (A-7), expanded by Kozmetsky and Kircher (C-6), and further refined by Homer (A-5). The Lieberman model takes the form of a series of matricies which show, successively, what items of data appear on each source document, what source documents are used to prepare which first-level reports, and so on, until the final matrix which shows what nth level reports are used to perform each of the business functions under investigation.

Lieberman defines:

(i) "B", a business function - a set of managerial activities which are assigned to a decision centre according to types of duties.

(ii) "C", a class of information - one or more pieces of information having all common qualities. This is composed of: a) "i", the identification class of information. This is information which describes or identifies certain data such as the date, department number, description of material, etc.

b) "q", the quantification class of information. This is information which shows amounts; that is, gives quantitative measures such as number of hours worked, etc.

(iii) "S", source data forms - upon which information is recorded for the first time.

(iv) "R", report forms - formed by performing operations on source data forms.

The matrix structure is built as follows:

(a) The Matrix of Source Data Forms, MS. If there are n classes of information and m forms, there will be n rows and m columns. Each intersection or "cell" will contain a 1 or 0, according to whether the information is used or not used in that particular form.

	S_1	S_2	S_3	----------	S_m
i_1	x_{11}	x_{12}	x_{13}	----------	x_{1m}
i_2	x_{21}				
-	⋮				⋮
-					
i_t					
q_1					
q_2					
-					
q_p	x_{n1}	x_{n2}	----------		x_{nm}

where: $x = 0$ or $x = 1$ and $p + t = n$

(b) The Matrices of Source Data Forms, used in the n report levels:

e.g. 1st Report Level R^1, 2nd Report Level R^2, etc.

$$M_1 = \begin{array}{c|cccc} & R^1_1 & R^1_2 & \text{-----} & R^1_p \\ \hline S_1 & y_{11} & y_{12} & \text{-----} & y_{1p} \\ S_2 & y_{21} & \text{---------} & & \\ - & - & & & \\ S_m & y_{m1} & \text{---------} & & y_{mp} \end{array} \qquad M_2 = \begin{array}{c|cccc} & R^2_1 & R^2_2 & \text{-----} & R^2_p \\ \hline R^1_1 & z_{11} & z_{12} & \text{-----} & z_{1p} \\ R^1_2 & z_{21} & \text{---------} & & \\ - & - & & & \\ R^1_p & z_{p1} & \text{---------} & & z_{pp} \end{array}$$

(c) The Matrix of Business Functions, MB. After some finite number of steps, the final matrix evolves, representing which functions use which report. Assume there are e report levels, and f business functions. Them MB, the final matrix, is:

$$MB = \begin{array}{c|cccc} & B_1 & B_2 & \text{--------} & B_f \\ \hline R^e_1 & w_{11} & w_{12} & \text{--------} & w_{1f} \\ R^e_2 & w_{21} & \text{----------} & & \\ - & - & & & \\ - & - & & & \\ R^e_e & w_{e1} & w_{e2} & \text{--------} & w_{ef} \end{array}$$

By simple matrix multiplication, each Report Level may be expressed in terms of any other level, or in terms of the initial Source Data Forms matrix. The ultimate multiplication is that of multiplying all matrices, from Source to Business Function. The result is of the form; $MSB = MS \cdot M_1 \cdot M_2 \cdot \text{----} \cdot M_e$.

$$
MSB = \begin{array}{c|cccc}
 & B_1 & B_2 & B_3 \text{ --------} & B_f \\
\hline
i_1 & v_{11} & v_{12} & v_{13} \text{ --------} & v_{1f} \\
i_2 & \vdots & & & \vdots \\
- & & & & \\
- & & & & \\
q_1 & & & & \\
- & & & & \\
q_p & v_{n1} & v_{n2} & \text{----------} & v_{nf}
\end{array}
$$

where v_{ij} = any positive number or 0, and the v indicates the number of times this classification of information is available to each function.

Any individual matrix in this system indicates the availability of information from one reporting level to the next. In the case of a source-data form, the appearance of a "1" indicates that a certain item of basic data in the set "C" is actually <u>used</u> in preparing the source-data report. In this case, the summation of the elements across any row gives the total extent to which that item is used in preparing all source-data reports. Similarly, the summation of any column shows the number of items that appear on a particular report. In the case of higher-level reports, the appearance of a "1" shows that information from one report is <u>available</u> to a higher-level report and that some of it is used, but <u>not</u> that <u>all</u> the information items from the lower-level report appear on the higher-level one. Thus, the row sums of these higher level matrices indicate the degree to which the information on the lower-level reports is transmitted upwards, and the column sums indicate the

complexity (in terms of the number of lower-level reports comprising the higher one) of the preparation of higher level reports.

The final matrix, resulting from the multiplication of all lower-level matrices up to some "business function", indicates the classes of information available to each function. Each element in the final matrix MSB will indicate the number of "routes" through which the item of information (i or q) is available to a certain function. This gives a measure of the redundancy in the transmission of data up through the report system "hierarchy"; i.e., the degree to which the same i's or q's appear on more than one source form, or that a source form appears on more than one report form, or both.

Finally, Lieverman suggests that this formulation so far only describes a part of the communications within the organization, the remainder being composed of an informal network which always exists augmenting the formal. It is then postulated that there are many alternative ways of representing this informal network, depending on the amount of information which can be obtained about it. One technique is to postulate that certain functions communicate with others informally on a fairly frequent basis. This communication might then be represented by the matrix IB, where:

$$IB = \begin{array}{c|cccc} & B_1 & B_2 & \text{--------} & B_f \\ \hline B_1 & u_{11} & u_{12} & \text{--------} & u_{1f} \\ B_2 & u_{21} & \text{----------} & & u_{2f} \\ - & - & & & \\ B_f & u_{f1} & \text{----------} & & u_{ff} \end{array} \qquad \text{where } u_{ij} = 1 \text{ or } 0$$

The formal network, MSB, might then be augmented by this informal one to form the total network by simply multiplying MSB by IB; i.e.

$$TMB = MSB \cdot IB$$

This is the basic matrix formulation proposed by Lieberman. Subsequently, several extensions of this approach have appeared, including those of Kozmetsky and Kircher[1] who have proposed refinements introducing a time factor, modifications of the informal network representation, and a formulation for evaluating the system based on systems studies. In addition, Homer[2] suggests that it is possible to establish a model, ASB, which depicts the ideal data requirements of each business function; thus,

$$CSB = MSB - ASB$$

gives an indication of the excess routing of data, or the lack of needed data, in the system. Homer also proposes two methods for overcoming the problem which arises when it is found that the matrices are incompatible for multiplication.

3.2.2 Results

This model represents a major break-through in quantitative theory of MIS's in that it was the first formulation of the "matching" process of information flow in which data inputs are matched with information requirements on the output side.

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1. Kozmetsky, Kircher, Electronic Computers and Management Control, McGraw-Hill, 1953, p. 275

2. E.D. Homer, "A Generalized Model for Analyzing Management Information Systems", Management Science, July, 1961, p. 500

The model, through the formulation of the matrix network, provides a useful, conceptual framework which enables the analyst to picture the whole of a very complex system in a relatively simplified form. The model also has several other advantages:

(a) It clarifies the relationship of the information system to the organizational structure. The report levels as defined in the model should tend to parallel the company's organizational levels, since the primary purpose of such a system is to convey decision-making information. Thus, such a formulation indicates where the bulk of the information is being sent, and presumably where the decisions are being made. Thus, the degree to which the MIS of the firm coincides with its managerial structure is highlighted.

(b) It permits experimentation and testing of the model to pre-determine the possible effects of proposed system changes.

(c) It delineates somewhat the relationship and importance of informal communication within the firm.

In addition, actual implementation of the matrix approach to analyzing MIS's provides insight into the many "micro" aspects of the information system, for example, the relationship between the amount of identification data being collected and the amount of quantification data, the <u>duplication</u> in identification data, etc. The results of such a system study are presented in Kozmetsky and Kircher, page 288.

3.2.3 Critical Analysis

While this matrix model provides a very useful conceptual

framework for analyzing a given MIS, it incorporates many abstracting and simplifying assumptions which make it difficult to apply in practice, and of limited value particularly to the area of MIS evaluation. First, the model pre-supposes that the input data requirements are known. While it seems impossible to obviate this assumption, it is rarely true in practice. (see Chapter 5). The same is true of other aspects of the formulation; for example, the model neatly categorizes the components of a system into data, source documents, various level reports, and business functions. Actual cases do not exhibit such clear-cut characteristics. For a more detailed description of this problem, see the article by Homer listed as A-5 in the Bibliography, page 503. Nor does the model adequately explore the important aspect of "feedback", in which the result of some business function might be the generation of a report which in turn is used in the preparation of another report, which affects other business functions, and so on.

Secondly, it seems likely that the matricies which would result from implementation of the model to any but the simplest of systems, would be of such great size as to make the formulation extremely cumbersome, particularly if the modifications proposed by Homer[3], which must be incorporated to produce matricies which are compatible for multiplication, are adopted. It is quite conceivable that the whole class "C" of the firm's input data might easily contain a number of items running well into

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3. ibid., p. 500

the thousands, while the number of intermediate and final level reports being produced might easily be several hundred, even for a fixed point in time. Such a huge matrix formulation could conceivably require far more effort than it is worth.

In addition, one of the main features of the matrix formulation is that it provides a measure of the redundancy in the collection and reporting of data. While redundancy is not particularly good in a MIS, it is not necessarily bad either, since it may serve, purposefully or not, to reduce errors both through cross-checking of processed data (such as the verification procedures used in data processing), and through management impact (i.e., the re-appearance of important items of information may insure that management uses or at least is aware of such information, much in the same way as "reminder" advertising is used for impact on the consumer).

Finally, the model offers little in the way of providing evaluation parameters. The basic difficulty is that the "economics" of the system are not adequately incorporated. There is no indication of the relative "value" of a report or set of reports to a business function, only of the fact that it (he) gets them. Neither is there consideration of information cost or inherent "noise" in the system, thus the effectiveness of the system and the effectiveness of the information being provided by the system remain indeterminant in the formulation.

3.3 A Decision-Theory Model

3.3.1 Formulation

Extensions of decision theory, and in particular Bayesian decision rules, are incorporated here in an approach to MIS evaluation which is particularly suitable for computerization. The approach is one of modelling the information system as a stochastic system in which any particular state of nature can give rise to several possible messages. The "decision rule" then specifies an optimal action for each message received. Given a "utility-index" associated with each act-state pair, the Bayesian criterion postulates that a decision rule will be optimal if its adoption maximizes the expected utility, using as weights the posterior probabilities which are computed by employing Bayes' Theorem. The value associated with an information system is then obtained by computing the expected gain (using the optimal decision rule) as a result of employing the system.

It then follows that an appropriate measure of effectiveness of a given information system to a particular user is the net gain in the expected utility resulting from employing the information system as an aid in decision-making processes, over and above the expected utility which results when no information system is employed. Thus, the information system effectiveness is consistent with the utilities chosen, and the statistical hypotheses concerning the prior uncertainty about the environment.

The usual decision-theory model includes the following definitions:

Let: x_j denote the jth state of nature, $j = 1, \ldots\ldots n$

: y_k denote the kth message received, $k = 1, \ldots\ldots m$

: a_i denote the ith act open to us, $i = 1, \ldots\ldots p$

: u_{ij} denote the utility index assigned to the act-state pair, (a_i, x_j), $u_{ij} = U(a_i, x_j)$

: R denote a decision-rule which assigns an act to each of the possible messages, $a = R(y)$

An information structure can then be characterized as:

		Message Transmitted	
		y_1 ----------	y_m
State of Nature	x_1	q_{11} ----------	q_{1m}
	⋮	⋮	⋮
	x_n	q_{n1} ----------	q_{nm}

where $q_{ik} = P(y_k/x_i)$ is the conditioned probability of the kth message, given the fact that the true state of nature is x_i.

The Bayesian decision-rule assumes the following things:

(i) There is a certain <u>prior</u> probability associated with each state of nature, $P(x_j)$.

(ii) For each message transmitted, a posterior probability distribution over the states of nature can be derived by using the theorem.

If $P(x_j/y_k)$ denotes the posterior probability of the

state x_j given the fact that y_k has been observed, then using the Bayes theorem, it is defined by:

$$P(x_j/y_k) = \frac{P(x_j) \cdot P(y_k/x_j)}{\sum_i P(x_i) \cdot P(y_k/x_i)}$$

Given the utility-index, u_{ij}, the expected value of an act, a_i, given the fact that y_k has been received, is denoted by:

$$V(a_i/y_k) = \sum_j P(x_j/y_k)\, u_{ij}$$

The Bayesian criterion then says that for each message, y_k, one should select the act $a_i = R(y_k)$ such that:

$$V(a_i/y_k) = \max_{a_i} V(a_i/y_k)$$

$$= \max_{a_i} \sum_j P(x_j/y_k)\, u_{ij}$$

For any given information system, S, then, the transmission probabilities $P(y_i/x_j)$ are specified. The probability of receiving the ith message given the prior probability distribution over x and the information system, S, is then:

$$P(y_i) = \sum_j P(x_j) \cdot P(y_i/x_j)$$

The Bayesian value of S then becomes:

$$\bar{V}(S) = \sum_i P(y_i)\, V(a_i/y_i)$$

$$= \sum_i P(y_i) \max_{a_i} \sum_j P(x_j/y_i)\, u(a_i, x_j) \quad (I)$$

where, as given before, $P(x_j/y_i) = \dfrac{P(y_i/x_j) \cdot P(x_j)}{P(y_i)}$, and the

$P(y_i/x_j)$ can be directly specified once the statistical nature of the error processes in the information system is known.

This formulation suggests that the effectiveness of an information system, $E(S)$, may be considered as the net gain in the expected utility, resulting from employing the information system as an aid in the decision-making processes, over and above the expected utility which results when no information system is employed. That is:

$$E(S) = \overline{V}(S) - \overline{V}(S_o) \qquad (2)$$

where S_o is the null information system defined by $P(x_j/y_i) = P(x_j)$ for all i and j.

Hence, $\overline{V}(S_o)$ is given by:

$$\begin{aligned} \overline{V}(S_o) &= \sum_i P(y_i) \max_{a_i} \sum_j P(x_j)\, u(a_i, x_j) \\ &= \max_{a_i} \sum_j P(x_j)\, u(a_i, x_j) \qquad (3) \\ &= \text{the value of information based on the } \underline{\text{prior}} \text{ probabilities only.} \end{aligned}$$

3.3.2 Results

These equations then allow the computation of the Bayesian effectiveness of the information system, S, characterized by the "noise" probabilities $P(y_i/x_j)$, and prior distribution $P(x_j)$. Since the normal procedure is to postulate a utility matrix relating the states of nature and the act space to the utility measure, the solution of equations (1), (2) and (3) constitutes problems of the mathematical programming type in which all the alternatives are evaluated (in most practical cases, no

algorithmic solution will exist).

Examples of Information Systems:

(i) The Null Information System

	y_1	----------	y_m
x_1	q_{11}	----------	q_{1m}
⋮	⋮		⋮
x_n	q_{n1}	----------	q_{nm}

$q_{ij} = q_{kj}$ for $j = 1, \ldots\ldots m$

The null information system serves as a lower bound for the Bayesian value of an information system, which is a measure of the best (according to the Bayesian criterion) a decision-maker can do without the aid of an information system. It should be noted that, since the effectiveness, E(S), measures the incremental value of an information system over and above the value of no information system, this measure is an indication to the decision-maker of how much he should be willing to pay for such a system, in terms of the decision-making benefit he may derive from it.

(ii) The Perfect Information System

	y_1		----------		y_m
x_1	1	0	-------		0
x_2	0	1			0
⋮	⋮		1		⋮
				1	
x_n	0	0	-------		1

i.e.,

$q_{ij} = 1$, if $i = j$

$q_{ij} = 0$, if $i \neq j$

The perfect information system serves as an upper bound for the Bayesian value of an information system, which is a measure of the best a decision-maker can do with the aid of perfect information. Such a bound will tell us what the maximum gain is that can be expected by improving the precision of an information system and whether an effort to improve the information system justifies its cost.

3.3.3 Critical Evaluation

Again, what has been developed is an interesting and useful statistical model which has quantified the nature and framework of MIS's, yet has obvious limitations with respect to practical evaluation of decision systems. This decision theory framework has the advantage over other approaches of including in the formulation the utility-structure at the decision centre, thereby incorporating the value of information considerations as discussed in Chapter 2. Thus, a system is selected which is designed to meet the needs of its eventual users. In addition, it is possible to test the sensitivity of a proposed system to changes in the utility and prior probability premises. Furthermore, the method is useful in verifying whether the utility structures of two or more distinct users are sufficiently congruent to warrant a joint design and the sharing of costs, or whether it is better to keep separate systems because the cost of compromising, in terms of lowered performance, is too high.

The model, however, incorporates much in the way of assumptions and simplification. Foremost among these are the

following:

(a) The model deals with a static decision situation. That is, it assumes the objective of representing the value to one particular user of an information channel characterised by fixed "noise" probabilities (the conditional probabilities of the information system), such as is the case in mechanized control systems used in the military (see Gagliardi, et al. in B-4 of the Bibliography, page 25), or statistical sampling systems used for quality control. Unfortunately, in general business applications the system must be designed to supply relevant information for many kinds of decisions, which may change both in number and nature even in the short run. In addition, the human component of business systems introduces a random element which makes the conditional probabilities of the system difficult to predict. Thus, the orientation of the model is to the modelling of relatively "tangible" and less complex systems than are encountered in business applications.

(b) This approach to analyzing information systems is somewhat limited in that it does not deal specifically with the reporting network of the system. The processing and reporting mechanics are assumed in the formulation of the "information structure", and thereby virtually ignored. This is in direct contrast to the Lieberman model, which deals with these exclusively, ignoring the essential "decision" context of the information system.

(c) The formulation does not permit a benefit-cost evaluation, but rather a value-added evaluation. That is, it

evaluates a system on the basis of its value over and above that of no system at all. Unfortunately, there is no indication of how much this added value might cost in terms of a better or more sophisticated MIS, and thus whether the cost is justified. While this is somewhat overcome by the fact that the incremental value gives an indication of how much the decision-maker should be willing to pay for the system, or by referring to net utilities as does Marschak,[4] the many difficulties of formulating the cost side of evaluation are nevertheless assumed away.

(d) Finally, the model adopts the basic assumptions of decision theory: that the relevant states of nature are known and can be listed exhaustively; that the decision-maker's prior probability distribution over the states of nature is known; that the "messages" (y_i) output from the system are known and are mutually exclusive; and that a meaningful utility measure can be derived. In practice, these factors are difficult, if not impossible to arrive at since, in many cases, management will be able to provide little more that hazy guesses. In addition, the computations involved may be astronomical, as the number of possible system configurations (see Chapter 4), which determine the conditional distributions, $P(y/x)$ and $P(x/y)$, may approach infinity. For large systems, the computational costs may well be prohibitive.

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4. J. Marschak, K. Miyasawa, "Economic Comparability of Information Systems", Western Management Science Institute, U.C.L.A., Working Paper No. 85, July, 1965, p. 13

Note: Some Extensions

For a theoretical but interesting extension of this kind of an approach, and one which incorporates the theory of "teams", the reader is referred to the paper by Kriebel listed in the Bibliography as B-5.

In addition, Marschak (see B-7, B-8, and B-9) and his co-authors have done extensive work in the area of MIS's, in particular the application of decision theory and information theory. This work is also highly quantitative and theoretical, yet it provides several different aspects which are of interest.

CHAPTER 4

INTEGRATION OF THE MODELLING APPROACHES

4.1 Introduction and List of Variables

The preceding formulations illustrate the difficulties facing quantitative approaches to evaluating MIS's. The matrix model indicates the basic problems of description (i.e., the difficulty in adequately formalizing the many complexities and interrelationships in these systems), while the decision-theory approach illustrates the problem of deriving measurable, sufficient parameters for benefit-cost analysis (i.e., the inadequacy of conventional "dollar measures" in evaluating information value, due to the probabilistic nature of the decision-making process under uncertainty). The matrix approach, which assumes away the value of information, can be extended (see Kozmetsky and Kircher, C-6 in the Bibliography) to yield cost indicators insofar as they relate to complexity, redundancy and routing specifications, while the decision-theory model, which assumes away reporting difficulties and costs of information, provides a measure for value-effectiveness. But the logical approach to MIS evaluation (see Chapter 2) is that of determining to what extent a given MIS optimizes the value-cost trade-off; that is, at what point along the information axis of Figure 3 is the system operating? Thus, for proper evaluation, both

value and cost aspects must be formalized. Unfortunately, neither of these approaches permits this kind of thorough analysis, even in abstract formulation.

One method of resolving this difficulty would seem to be the integration of the two approaches to derive a more inclusive model. This would them permit the adoption of both the reporting system considerations of the matrix model and the probabilistic decision-making information values of the decision-theory approach. In addition, a more comprehensive model would provide an evaluation tool which more closely coincides with the appropriate benefit-cost approach mentioned above, since both value and cost parameters could be derived. One drawback to such an approach which becomes immediately clear, however, is that in order to integrate the two approaches, one must adopt the restricting and simplifying assumptions of both. However, since one purpose of this thesis is to illuminate the assumptions necessary to quantify MIS's for evaluation purposes (see Chapter 5), this difficulty is immaterial. The follwoing formulation is offered as providing an integrated approach which overcomes many of the difficulties of the previous methods.

Before beginning the formulation, for purposes of clarification the following is a list of variables to be used in the analysis:

$S = \{s_i\}$ - the set of the states of nature relevant to the decision problems at hand.

$B = \{b_j\}$ - the set of basic data inputs to the reporting system.

$A = \{a_k\}$ - the set of actions open to the decision-maker

$R = \{R_p^i\}$ - the set of all the reports generated in the MIS, where R_p^i is the set of all reports produced at level i in the organization, i.e., $R^i = \{R_p\}$

$B_p^i = \{b_j^p\}$ - the subset of B consisting of the basic data pieces used in report R_p^i.

4.2 Formulation

Any MIS can be regarded as including three basic activities: information generation (procurement), processing, and reporting. The purpose of any MIS is to procure data relevant to management decision-making, to process it into appropriate formats of information, and to transmit this information as efficiently as possible to the decision-centres of the firm. Three basic questions facing the information-analyst are, then:

(i) To what degree does the basic data being collected represent the problem (be it in the internal operations of the firm or its environment) facing the decision-maker; i.e. - is the correct amount of relevant data being collected initially?

(ii) Is the procured data being processed into formats which are optimal for use by the decision-maker, or is the value of the basic data for decision-making being reduced by poor formats or incomprehensible reports?

(iii) Is the MIS routing the data correctly to the appro-

priate decision-centres of the firm; i.e., is each decision-maker utilizing the full "value potential" of information being collected?

To answer these questions, it will be postulated, as in the Lieberman model, that the information system of the firm can be represented by a series of Reporting-Level matrices. The first matrix will represent the "procurement" activity of the MIS, and will be termed the Procurement Matrix, PM. The row vectors of this matrix, s_i, will represent the states of nature or the decision-making environment (external or internal to the firm), while the column vectors, b_j, represent the basic data inputs to the MIS. The elements of PM will be the probabilities $P(b_j/s_i)$, and will represent the degree to which the procurement or "sensor" system is error prone; i.e., how closely the basic data pieces represent the relevant states of nature. The procurement matrix, PM, is then of the form:

Basic Data (Inputs to the reporting system)

		b_1	b_2	b_3	----------	b_m
	s_1	x_{11}	x_{12}	x_{13}	----------	x_{1m}
States	s_2	x_{21}				⋮
of	s_3	x_{31}				⋮
Nature	⋮	⋮				⋮
	s_n	x_{n1}	----------	----------	----------	x_{nm}

where the $x_{ij} = P(b_j/s_i)$, the conditional "procurement" probabilities.

In a given decision-making situation, these pieces of basic data, b_k, will have a certain <u>value</u> associated with the reduction of uncertainty provided by the basic data and the utility structure of the decision-maker. This value is given by the expected utility of an action, a_k, <u>given</u> basic data, b_d, less the expected utility of a_k with <u>no</u> information; i.e.,

$$V(a_k/b_d) = \sum_i P(s_i/b_d)\, u(s_i,a_k) - \sum_i P(s_i)\, u(s_i,a_k)$$

where the $P(s_i/b_d)$ are the posterior probabilities which may be derived from the prior and conditional probabilities using Bayes theorem, or may simply be subjective estimates by the decision-maker, and the $u(s_i,a_k)$ are the act-state utilities of the decision-maker.

Similarly, the <u>potential</u> (maximum) value of the basic data is given by the value under an optimal decision-rule,; i.e.,

$$V^*(a_k/b_d) = \max_{a_k} V(a_k/b_d)$$

The reporting system conveys these basic data to the decicion-centres in a certain fashion. Again employing the matrix formulation, the system of reporting basic data to the first report level is represented by the matrix on the following page.

Similar matrices show the routing of data from report level 1, to level 2, to level 3, and so on up to the highest level. This formulation is similar to the basic Lieberman model, with the exception that "Business Functions" as he terms it,

will be considered decision-centres as defined in this thesis, and these will be considered to exist at <u>every</u> report level.

Reports at Level 1

		R_1^1	R_2^1	R_3^1	--------	R_m^1
Basic Data Inputs	b_1	y_{11}	y_{12}	y_{13}	--------	y_{1m}
	b_2	y_{21}				⋮
	b_3	y_{31}				⋮
	⋮	⋮				⋮
	b_n	y_{n1}	----------	----------	----------	y_{nm}

where $y_{ij} = 0$ if the piece b_j is not contained in report R_p^1 and $y_{ij} = 1$ if it is.

Considering the first report level, then, the maximum potential utility associated with any report, R_p^1, will be the sum of the potential values of the basic data which are contained in that report, assuming proper usage and format; that is,

$$U(R_p^1) = \sum_{B_j^1} V^*(a_k/b_j)$$

where $B_j^1 = \{b_j^1\}$, the subset of $\{b_j\}$ which is contained in report R_p^1.

Since the basic data are being procured with some degree of uncertainty regarding their relevance, (i.e., the conditional probabilities of basic data representing the relevant states of nature is less than one), the Bayesian Value of Report R_p^1 can be computed by weighting these basic data values, V^*, by their total probability of being relevant; i.e.,

$$\text{Bayesian Value of } R_p^1 = V(R_p^1) = \underset{B_j^1}{\mathcal{E}} P(b_j)\, V^*(a_k/b_j)$$

where $P(b_j) = \underset{i}{\mathcal{E}} P(s_i)\, P(b_j/s_i)$

= the total likelihood of b_j's being relevant to the decision problem at hand; that is, the probability that b_j represents the state of nature which, when combined with optimal act, a_k^*, yields the utility value V^*.

It should be noted that the basic data values were originally assigned on the basis of <u>optimal</u> decision-making, assuming the data was eventually portrayed correctly to the decision making functions. Thus the basic data values represent <u>potentials</u> of the procurement system, and what we are now trying to accomplish is the selection of a <u>reporting</u> system which will most nearly realize this procurement system potential. Since, as given by the matrix formulation, the reporting system up to some decision-making level may be represented by a matrix relating the basic data inputs to their eventual destination, this selection will amount to choosing the particular set of basic data routes through the information system which maximizes the <u>value</u> of the system; i.e., we are striving to

$$\underset{B_p^i}{\text{Maximize}} \quad V(R_p^1) \,/\, V^*\,(a_k/b_j)$$

This is the reverse of the procedure followed by Gagliardi et al in the decision-theory formulation described in Chapter 3, where the optimality of the reporting system is ignored, and the <u>procurement</u> (sensor) system is chosen so as to maximize

the total Bayesian value.

For simplicity, let us assume that all results are measurable in terms of money, and that the utility functions of money gains are linear for all decision-makers involved. The data values throughout are then additive and the total value of all reports, up to any given level "g" will be given by:

$$V_g(R) = \sum_i^g \sum_p V(R_p^i)$$

= the total value of the reporting system, R, composed of any number of reports, R_p^i up to the level R_p^g.

Associated with reporting system R will be a total cost, composed of a procurement system cost, a processing cost, and a reporting system cost. The problem of MIS evaluation is to measure the degree to which it is possible to maximize the difference between this total system <u>value</u>, V(R), and its <u>cost</u>; i.e.,

$$\text{Maximize } D_g(R) = V_g(R) - C_g(R)$$

by choosing the optimal combination of procurement and reporting systems. For the procurement system this implies choosing a method of gathering input data, b_j, of maximum relevance (and thus <u>value</u>) at least cost. For the reporting system this means choosing an optimal <u>routing</u> system of these basic inputs to the levels at which they are useful in decision-making.

4.3 Results

This formulation has attempted to yield parameters for judging the effectiveness of MIS's which are consistent with

the approach dictated by the economic analysis presented in Chapter 2. The total effectiveness of the system is given by:

$$D_g(R) = V_g(R) - C_g(R)$$

where: $D_g(R)$ = the "net benefit of the system (procurement and reporting) over and above its cost. As given in Chapter 2, there will be some <u>optimum</u> level of information quality and quantity which will <u>maximize</u> this net benefit. The efficiency of the system relative to this optimum, $D(R^*)$, is then given by:

$$\text{Eff } (R) = D_g(R) \,/\, D_g(R^*)$$

: $V_g(R)$ = the total value of the MIS to level g

$$= \sum_i^g \sum_p V(R_p^i)$$

$$= \sum_i \sum_p \sum_{B_j^i} P(b_j)\ V^*(a_k/b_j)$$

$$= \sum_i \sum_p \sum_{B_j^i} P(b_j) \operatorname*{Max}_{a_k} V(a_k/b_j)$$

: $C_g(R)$ = the total cost of the MIS to level g

= the sum of the <u>reporting</u> system cost to level g and the <u>procurement</u> system cost.

$$= C_g(R.S.) + C(P.S.)$$

As pointed out by the originators of the matrix system (see A-5, A-7 and C-6 in the Bibliography), some indications of system costs are given by the complexity and redundancy characteristics which are quantified by the matrix manipulation.

However, much remains to be done on this side of the evaluation process, since, as pointed out in Chapter 2, the cost function of information is quite complex.

CHAPTER 5

SOME EXTENSIONS: IMPLICATIONS FOR DESIGN AND EVALUATION OF MIS'S

In order to formulate the preceding models, many assumptions have been made, explicitly and implicitly, which abstract the formulations somewhat from situations in the real world. These assumptions concern the nature of information itself, the flows of information in the firm, and the characteristics of the decision-centres which use this information. The assumptions and limitations of the matrix and decision-theory approaches have been pointed out in Chapter 3 and, as stated in Chapter 4, the integrated approach embodies the assumptions of both. These assumptions will not be re-enumerated here; rather, the attempt will be made to pick out several of the more critical restrictions and discuss their implications on real world design and evaluation of MIS's. These assumptions are:

(1) The critical assumption of the matrix formulation - that the basic data requirements relevant for decision-making are known. In actual practice, the analyst usually proceeds on the basis of asking management what they need. However, as Ackoff points out:[1]

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1. R.L. Ackoff, op. cit., p. B-149

> "For a manager to know what information he needs, he must be aware of each type of decision he should make (as well as does) and he must have an adequate model of each. These conditions are seldom satisfied. Most managers have some conception of at least some of the types of decisions they must make. Their conceptions, however, are likely to be deficient in a very critical way, a way that follows from an important principle of scientific economy: the less we understand a phenomenon, the more variables we require to explain it. Hence, the manager who does not understand the phenomenon he controls plays it "safe" and, with respect to information, wants "everything". The MIS designer, who has even less understanding of the relevant phenomenon than the manager, tries to provide even more than everything. He thereby increases what is already an overload of irrelevant information."

Thus, the difficulty of determining information requirements is a very real one, and one which is virtually impossible to overcome, when, in addition, it is evident that information needs will likely change over time, as the firm's environment changes, the nature of its business changes, and the composition of its decision system changes.

This problem, and others to be discussed later, has led to the design of modular, data-based information procurement systems which collect and store a "base" of data in several modules, one for each functional area of the firm. This data base can then be searched for relevant information as needed by management for planning and control. Such a system is pictured in Figure 4.

(2) One basic assumption of the decision-theory approach is that a particular utility structure can be specified, usually by a ranking of all possible outcomes, based on the preferences of the decision-maker. This implies two things: one

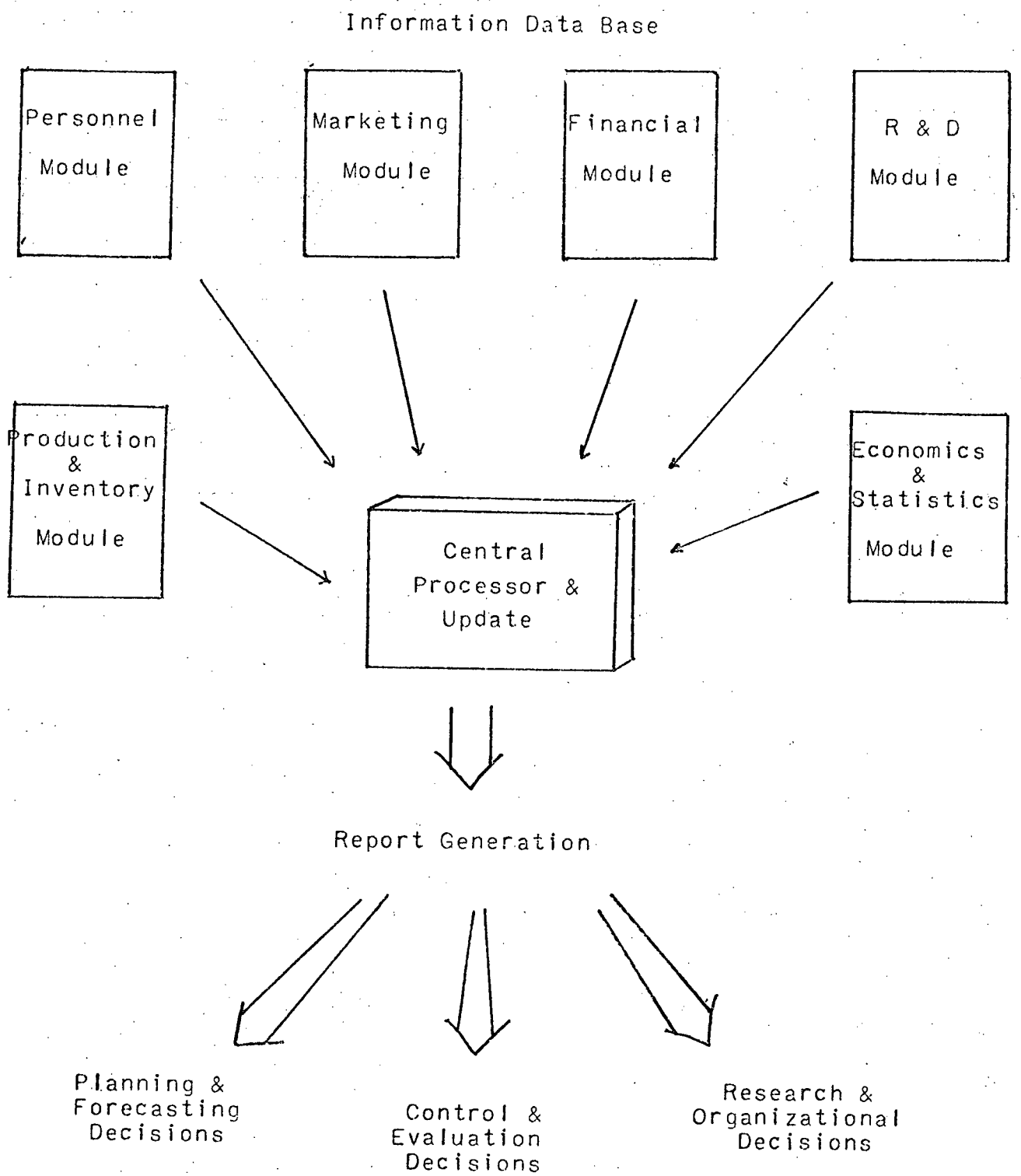
that the utility structure depends on the subjective value judgemens of one decision-maker or group, so that the criteria may lack universal appeal throughout the organization; and secondly, that even for a single decision-maker, this utility structure may vary over time, changing the kind of system preferred.

Again, the fact that the MIS of any corporation is very likely to be a dynamic structure rather than the static systems portrayed by these models is evident. In addition, while utility measures may be developed in certain specific applications (see for example B-4 in the Bibliography), in general it will be difficult to determine such utilities (particularly additive ones), thus making the assignment of information values nearly impossible. In the absence of these values, MIS effectiveness must be measured in terms of costs only, thus tying the system to the availability of funds, and leaving the systems manager virtually in the dark regarding the return being generated from the application of such funds.

Such considerations point to the importance of flexibility in original systems design, and one method of achieving this is through the modular approach illustrated in Figure 4, in which there is no fixed reporting system past the "module" (middle management) stage, and in which the basic system structure can be altered to meet the needs of management by simply adding or deleting modules.

(3) The psychological and sociological aspects of human decision-making systems are often ignored in quantitative analysis, yet they present very real problems to the information

Figure 4 A GENERALIZED MODULAR MIS



system analyst. Some of the more prominent aspects are:

(a) That decision-makers in the firm are not the isolated items presented in modelling approaches. They interact and communicate freely with other members of the system outside the formal communication channels, and also with other groups outside the firm itself. This kind of communication normally will not follow any regular pattern, nor is it usually predictable, even by the manager himself. For this reason, these informal information systems usually defy formalization, yet they will often significantly augment (or even supplant in some cases) the formal MIS, and thus have major effects on decision-making. The author is aware of several instances in which the formal MIS of the firm became increasingly less important to management the higher up in the organizational hierarchy the decision-maker was, up to the most senior position where the executive(s) would use the formal MIS perhaps only fifty percent of the time, the remainder of the information coming from personal contacts, associates in the industry or profession, etc.

(b) That associated with each decision-centre will be a maximum amount of input data that he can reasonably digest. This has been mentioned previously in the reference to Ackoff's article. The constraint on the amount of information which can be processed will be at least a partial function of the format in which the information is portrayed to the decision-centre. Relevant information is an aid to decision-making only if it is concise and clear and can be discerned and used

by the manager. Two implications become apparent here: first, that more relevant information may be supplied to a manager and not produce an "input overload" if it is properly organized and concisely portrayed; and secondly, that different displays of the same basic data may produce different total report value, reflecting the preference of the decision-maker for one format over another. An example of this is given by the preferences of some managers for graphs over tables of numbers (and vice versa).

While this aspect could be the subject of a thesis in itself, it should be mentioned in passing that considerations such as these make the report values, $V(R_p^i)$ and reporting system values, $V_g(R)$, very difficult to maximize since it no longer becomes a matter of simply choosing a set of valued data which yields a maximum report value; rather, the problem is one of choosing that combination and display of basic data which produces the most useful report (i.e., the information values are not additive).

(c) That the decision process is complex and very much a function of the individual capabilites of the decision-maker. The mistake is often made of assuming that if a manager is provided with the information he needs, he will then have no problem in using it effectively. As Ackoff points out: "The history of OR stands to the contrary."[2] He then goes on to cite several instances in which this became evident.

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2. ibid., p. B-150

Again, while an extensive treatment is impossible here, it should be pointed out that a key function in MIS design (and yet another factor pointing to the importance of flexibility in these systems) is the determination of exactly how well managers can use supposedly "needed" information. Where possible, the decision process should be aided by providing decision rules and performance feedback so the decision-centres can identify and learn from their mistakes. This again makes a MIS flexible and independent of the individual decision processes. For further analysis of this problem, the reader is referred to items A-6 and C-4 in the Bibliography.

CHAPTER 6

SUMMARY

Of the many areas of study currently examining the problem of MIS evaluation, the two judged most fruitful and comprehensive are the Lieberman matrix approach and the decision-theory approach adopted by the statistical mathematicians. These methods provide valid and reasonably practical techniques for envisaging the information-processing system of the firm, and in addition are suitable for computerization. However, the economic aspects of information and MIS's dictate a more comprehensive formulation than is provided by either approach. This thesis has attempted to demonstrate the validity and limitations of the approaches, to integrate the approaches into a more comprehensive formulation which is more in accordance with the principles of economics, and to indicate several implications which these approaches cast on the real-life analysis of MIS's.

In Chapter 2, the characteristics of information which contribute to value and cost were presented and the shape of the value and cost functions for each was proposed. Given these functions, guidelines were then established for evaluating MIS's on an economic basis which dictated that such systems should operate at a point where the value-cost differential was the

greatest. The difficulties of such an approach, given the nature of decision-making information and the existence of uncertainty, were outlined.

Two attempts at formalizing MIS's in quantitative terms were presented in Chapter 3. A matrix model, first proposed by Lieberman, (A-7), was outlined, and the merits and drawbacks of such an approach were discussed. The limitations of the formulation with respect to value measures led into the presentation of a decision-theory model proposed by Gagliardi, Ying and Holt (B-3). This model yielded efficiency parameters in terms of information value in decision-making, but ignored both the costs of information and the complexities of corporate reporting systems.

The attempt was made in Chapter 4 to integrate these two approaches, and in so doing to propose a more generally applicable model and one which yields effectiveness parameters in terms of both value and cost. The MIS of the firm was proposed as being composed of both a procurement system, which initially acquires the data, and a reporting system, which routes the data to management. The value of such a MIS was related to both the degree to which relevant information is acquired by the procurement system, and to the method in which it is routed to the decision-making function. The cost of such a system was then described as being composed of both procurement and reporting costs, where some indication of such costs is given by the complexity of the matrices describing each system.

The overall effectiveness of such a system is then the value - cost differential, and the relative efficiency, in accordance with the economic guidelines of Chapter 2, is measured by the degree to which this differential is maximized.

Several implications of these theoretical approaches on actual, practical MIS evaluation were then discussed in Chapter 5. The assumption of known information requirements in the matrix model was related in the real world to the difficulty analysts often have in pinning down what should actually be the inputs to such a system, and the relevant article by Ackoff (A-1) was cited. The utility assumptions of the decision-theory model were related to the difficulty of measuring the relative value of information to both the individual decision-maker (due to changing utility over time) and to the firm as a whole (due to differing individual utilities). Both of these implications highlighted the necessity for flexibility in MIS design, and this was proposed as one reason for the emergence of modular, data-based computer systems. Finally, three "human-factors" inherent in MIS's were discussed briefly - the existence of informal MIS's, the data-processing limitations of the individual decision-maker, and the complexity of the human decision-making process.

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