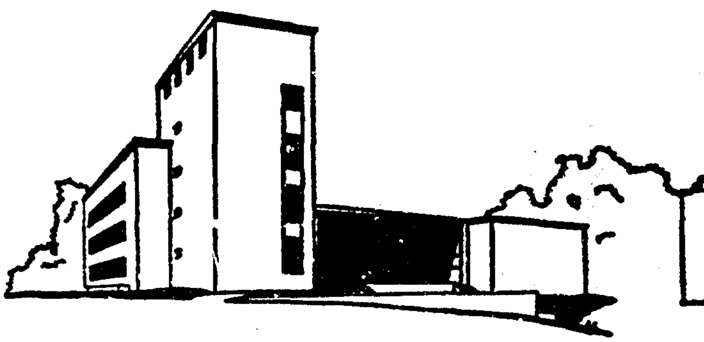
Carnegie-Mellon University

PITTSBURGH, PENNSYLVANIA 15213

GRADUATE SCHOOL OF INDUSTRIAL ADMINISTRATION

WILLIAM LARIMER MELLON, FOUNDER



W.P. #42-70-1

Management Sciences Research Report No. 226

THE EVALUATION OF MANAGEMENT INFORMATION SYSTEMS*

by

Charles H. Kriebel

September 1970

* Invited presentation, "MIS Copenhagen 70", International Conference on Management Information Systems, organized by the Danish IFIP Administrative Data Processing Group (DIAG), 14-16 October 1970, Elsinore, Denmark.

Management Sciences Research Group
Graduate School of Industrial Administration
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

ABSTRACT

During the past decade, the phrase "management information systems" or the acronym "MIS" has become increasingly popular for discussions of information processing support for management activities. Primary developments in the field of MIS have been paced by advances in computer system technology. The rationale and economic utilization of this technology within management organizations has posed some fundamental issues for system design, particularly among professionals who view "design" as a normative science. This essay reviews these issues as they relate to the stage in design called "evaluation". Specifically: What does the literature propose on MIS evaluation and what is being done in practice? What is the state-of-the-art today? What problems loom ahead?

1. Introduction and Overview

In the spring of 1968 Professor Herbert A. Simon delivered the Karl Taylor Compton lectures at the Massachusetts Institute of Technology on "the sciences of the artificial" -- cf. Simon (1969). At the risk of oversimplification, Simon's thesis in these lectures was that certain phenomena are artificial in a very specific sense: they are as they are only because a system has been molded, by goals or purposes, to the environment in which it lives. By way of contrast, the scientific disciplines have traditionally concerned natural phenomena: how they are and how they work. Today, one also observes studies of artificial phenomena: how to make artifacts that have desired properties and how to design.

What is the process called "design"? Is it art or science? In simple terms: design is decision making. It involves finding alternatives to change existing situations into preferred situations. For the engineer's analogy of the black box, it concerns re-configuring the interval environment of the box, so that given inputs yield desired outputs. The problem focus in design is the interface between the natural laws within a system and the natural laws without it. A designer is concerned with attaining goals by adapting characteristics of the former to the latter, and the process by which the adaptation of means to environments is brought about. If this process is unique to an individual and cannot be promulgated, the design is art. If through research and understanding, however, we establish normative principles to guide the process and can teach these rudiments to practitioners, then we may speak of a "science of design." (To quote a French scholar: "Art is I. Science is we.") Today, the discipline of design has emerged as an "artificial science" in common with such professions as engineering, architecture, medicine, law and management.

During the past decade, the phrase "management information systems" or the acronym "MIS" has become increasingly popular for discussions of information processing support for management activities. The phrase in one sense is more descriptive of the end-user's goals for the information system (computer-based and otherwise) than the earlier terminology of "business data processing". For convenience here, I forgo a discussion of the etymology and semantics of MIS, and will assume the phrase is synonymous with the several near equivalents appearing in the literature.

Much has been written on the subject of MIS, pariticularly on the process of system design, development and implementation. Indeed, most introductory textbooks provide flowcharts in an early chapter of each stage in systems development -- often including "cookbook" recipes and checklists of "do's and don'ts", occasionally documented by the author's personal experiences. Since these flowcharts are commonplace and reasonably consistent, there is no need to reproduce them. Rather in the space of this essay, I wish to consider one aspect of the design and development process, namely: the milestone called evaluation. In particular, given a conceptual model of the design process that involves goal-directed search: What does the literature propose on MIS evaluation? What is being done in practice? What is the state-of-the-art today?

2. The Problem: Information Economics

The issue of evaluation is conceptually straightforward. That is, one seeks to observe and measure output (results) within the framework of some "model" which describes the system environment (and interface) in terms of available resources, their capacities, given inputs, and criteria of performance on stated goals. As a technical matter one would optimize the performance criteria, or at least for any pairwise comparison of alternatives prefer the one which was more efficient under the stipulated measure of performance. Such a decision paradigm may be relatively easy, say, for the engineering consideration of a piece of capital equipment, e.g., most accountants would employ a net-present-value criterion for the discounted "cash flow" of dollars associated with the investment. The decision becomes more difficult, however, when the investment involves a configuration of general purpose resources and the end-use alternatives of the resources must be included within the evaluation.

Information theory in communications engineering provides a formal framework for measuring the quantity of information and communications efficiency, cf. Hartley (1928) or Shannon and Weaver (1948). In simple terms information theory is concerned with the activities of a "source" who encodes a message, a "communications channel" which transmits the coded message, and a "receiver" who decodes the message upon receipt. As such the theory says nothing about the activities of either the "source" or the "receiver" outside the stated symbol processing system and, more specifically, it tells nothing of the value of the message communicated to the end user. (For example, was it "Mary had a little lamb" or "We are at war"?)

Decision theory in economics and statistics provides a formal framework for measuring the value of information to a decision maker, cf. Wald (1950) or Raiffa (1968). In its simplest form, the decision theory model postulates an individual who must select a terminal action on the basis of either current information or additional information he can purchase, the outcome payoff being a function of the action selected and an uncertain event outside his control. This single-person model has been generalized under certain restrictive assumptions on behavior to multi-person organizations through a framework called "the theory of teams," cf. Marschak (1955) and Radner (1962). More recently, Marschak has attempted to link the team decision model with the communications model of information theory, in effect, by preceding the "source" with an "observer" and following the "receiver" with a "decision-maker", cf. Marschak (1968) and Chapter 3 in Kriebel, et al (1970). Other variations of the classical decision theory model are also beginning to appear in the literature of contemporary economics.[1/]

The important aspect of this literature, irrespective of modeling details, is that decision theory provides the relevant theorem on information economics for system evaluation. Specifically, the expected value of information to a manager (i.e.,

---

[1/] For example, see the Program and Abstracts of Papers: Second World Congress of the Econometric Society (8-14 September 1970; Cambridge, England), particularly pages 47, 60, 95, 104, 120, 166, 187, and 215.

decision maker) is computed from the expected net gain (benefits less cost) of his decision rule (strategy) including the information less the rule excluding that inf rmation, where mathematical expectations are calculated on a rational basis according to a priori probabilities. That is, information has value if its expected net gain is positive when computed according to the algorithm. To implement the theorem management must structure the decision problem such that the decision mechanism or rule for choosing terminal actions is made explicit, the space of outcomes is specified and ranked in order of preference (payoff), and information opportunities on uncertainties are encoded in terms of probability distributions. Do these requirements effectively preclude application of the procedure in any complex real world environment?

In general, I think the answer to this question is: no. Certainly, the broad principle of positive expected value is rational and consistent with our ex ante intuition. Furthermore, for many non-trivial situations -- if not at the "total MIS" level, perhaps -- the computations and analysis can be performed exactly. More broadly, however, it is important to recognize that the comparative gains of technology in information processing have been realized <u>only</u> by <u>formal</u> <u>information</u> <u>systems</u> in organizations. That is, the orders of magnitude increase in data processing efficiencies have been realized over the past decade through capital-intensive technology applied to formalized systems. In contrast, informal information systems which tend to be labor-intensive have not been affected by the economies and leverage of computers. For the foreseeable future, the demand for information processing capacity by managers and organizations appears ever increasing. To expand the supply and ability to service these demands will require increasing reliance on formal information systems and capital-based technology. Thus, the management information systems that we seek to design and evaluate will require specificity and explicit statements of decision mechanisms, uncertainty encoding, and the like, to the degree that they become formalized. To this degree, I think the decision theory construct for information value serves as a useful criteria in design.

Maybe, I have overstated the case for theory in making the point for economic relevance. Certainly, the task of incorporating a representative characterization of the technology into a formal model is a major hurdle in evaluation, and many non-economic factors will influence the final design. For example, Figure 1 might be considered as one macro-flowchart which diagrams the "bare bones" structure of an MIS. Without dwelling on the details of the illustration, it is apparent that people are prominently involved as symbol processors in many stages of the cycle, and behavioral considerations will often dominate given situations. Figure 1 also highlights the sub-system role of data processing technology within the broader designation of a formal MIS. At this juncture it may be constructive to briefly consider the problem of evaluating the technological component of an MIS before returning to the broader issue.

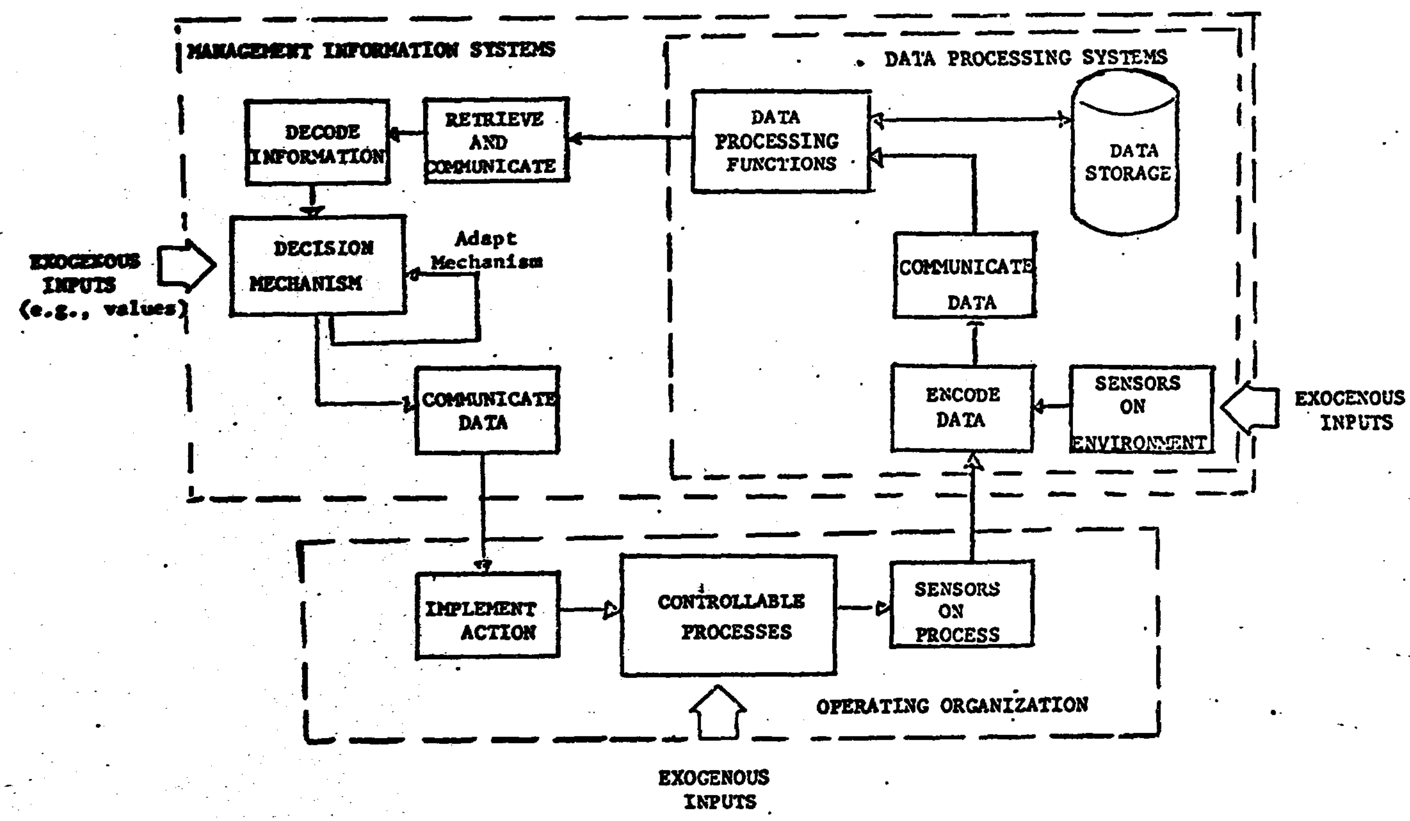
3. The Evaluation of Information Processing Technology

Progress in building information processing hardware has far outdistanced progress in evaluating the performance of this technology in systems. As Sharpe (1969) recently remarked in his excellent book, it is one thing to write out a series of equations which purport to functionally describe a computer configuration, its another matter to obtain the true parameters and functions which pertain to an actual configuration.

For example, Henderson (1960) proposed an integer linear programming formulation of the problem of data processing design

Figure 1

The Structure of an M.I.S.



for an organization. In Henderson's model data requirements, report content and interrelations, data flows, processing capacities and technological constraints, etc. were to be specified in the form of constraints and the linear criterion function of net benefits was to be maximized. Perhaps not too surprisingly, Henderson's model was not empirically-based and included the additional caveat that as presented the model was too large for existing (1960) computers and known linear-integer programming algorithms -- the latter qualification is still true today.[1/] Similar linear programming models for computer selection have also appeared in the literature, e.g., Schneidewind (1966), where the criterion is cost minimization subject to given performance constraints. To date, the prospects for a completely objective model, such as LP, as a solution procedure do not appear particularly promising. Beyond the computational problem, the biggest obstacle appears to be the likelihood that the user (designer) can capture all of the interrelations and empirical measurements needed for a "statement" of performance requirements. For example, consider the difficulty of specifying the requisite detail for the factors listed in Table 1. A survey of other formalized models for design and evaluation is provided in Kriebel (1967) -- see also Sharpe (1969), Chapters 8-11.

At the opposite extreme of the completely "objective" mathematical model of the total system is the subjective approach, perhaps exemplified by "competitive bidding". As commonly practiced today, the user effectively delegates the computer configuration design to the manufacturer by first preparing a "statement" of system requirements and then soliciting competitive bids from vendors on various system alternatives. In this regard the user may attempt to employ one of several informal decision models for the cost/value evaluation of proposals. For example, (1) the user specifies minimum performance and selects the minimum cost system

1/ Note the reference here is not a criticism of Henderson's model, per se; to the contrary his research was an early and immaginative delination of the design problem.

Table 1

DIMENSIONS OF SYSTEM REQUIREMENTS STATEMENT AND CONSTRAINTS

WORKLOAD: Applications
- Processing Functions
  - Inputs, Compilation, Computation, Control Data Acquisition, File Maintenance, Media Conversion, Sorting, Storage and Retrieval, Outputs, Processing Frequencies, Security/Privacy, Relative Priorities
- Development/Implementation Schedules
- Working Programs
- Production Operations Constraints
  - Data Volumes, Thruput,Turn-around Times, Response Times, User Priorities, Physical Space
- Etc.

HARDWARE: Units
- Channels, Control Units, Direct-access Devices, Storage, Tape/Disk/Drum Drives, Processors, Terminals, Unit Record Devices

Interfaces
- External Communication Networks, Man/Machine Interface, Other Computers, Recording Media

SOFTWARE: Source Language, Object Language
System Functions, Supervisory Programs, Data Management, File Design, Task Control

SYSTEM ORGANIZATION:
Conventional batch processing, Multiprocessing (Direct coupled Many Processors), Multiprogramming (Multitasking, Telecommunications, Multiple-access) Compatibility

DATA REPRESENTATION

PERSONNEL

OPERATIONS ORGANIZATION AND ADMINISTRATION

EDUCATION AND TRAINING

POLICY AND PROCEDURES

MANAGEMENT INTERFACE

ETC.

proposed; (2) the user specifies maximum cost and selects the maximum performance system proposed; or (3) the user specifies minimum performance and maximum cost, and selects the system having the maximum value/cost ratio, employing tie-breaking rules if necessary. A completely subjective procedure for the "competitive bid" approach suffers from all the obvious weaknesses of human judgment and error, conflict of interest with other goals, bias, inefficiencies, and so on. The "statement" of requirements in this case, if not as rigorous as implied by the total system model, must nevertheless attend to many of the same issues listed in Table 1. Furthermore, the imposition of any single rigid measure of performance and/or requirement for performance as a short-cut to the complete specification is almost assured to lead to a sub-optimal (and perhaps grossly inferior) result. For example, consider the relative uselessness of a single performance index for a computer, say "cycle time", as a basis for system evaluation. One concludes from experience that some middle ground between the complete model and a subjective procedure is more likely to lead to preferred and realistic results.

Pursuing the middle ground to technology evaluation the most common objective methods employed to guide a subjective decision process include: figures of merit, scoring systems, or instruction mixes; kernel timing estimates; (so-called) benchmark programs; and simulations. The first method may range from a fairly simple expression (such as: maximize the log {memory size/cycle time}) for performance of alternative hardware, to more lengthy formulas which subjectively weight non-hardware characteristics (such as, adaptability, supplier support, and so on) -- cf., Solomon (1966), Bromley (1965), Arbuckle (1966) and Knight (1963). Although relatively simple to use the difficulty with these methods lies in their highly subjective specification and myopic view of the larger problem. For example, through such a formula, one can obtain the result that doubling the capacity of high speed core will double the thruput of a system -- which is absurd.

Kernel timing estimates are often employed for cost comparison among computers to perform a given task. Calingaert (1967) defines a program kernel as "the central processor coding required to execute a task of the order of magnitude of calculating a social security tax, inverting a matrix, or evaluating a polynomial". In comparing estimates one assumes equal efficiency and sophistication of the coding in assembly language for the various machine alternatives, cf. IBM (1965). Benchmark programs differ from kernels in that they typically represent programs (or problems) which exist on a current system and for which execution times are desired on a proposed system. Alternatively, the Auerbach Corporation considers six benchmark problems for evaluation purposes: updating sequential files, updating files on random-access storage, sorting, matrix inversion, evaluation of complex equations, and statistical computations, cf. Hillegass (1966). The final extension of replicating "representative" data processing workloads or requirements is to employ simulation. In addition to in-house or proprietary simulators several commercially packaged simulations have appeared on the market. A summary of the characteristics of three such packages is shown in Table 2; see Bairstow (1970). While simulation packages represent advance stage models they still suffer from the subjectivity of requirements specifications by the user (customer), they may present biased results, and, as indicated by Table 2, the commercial packages are relatively expensive.

Evaluating hardware technology -- the central processor, peripherals, and configuration alternatives -- is complex, but the inclusion of software performance considerably adds to the scope of the problem, cf. Calingaert (1967). Even though the "unbundling

Table 2

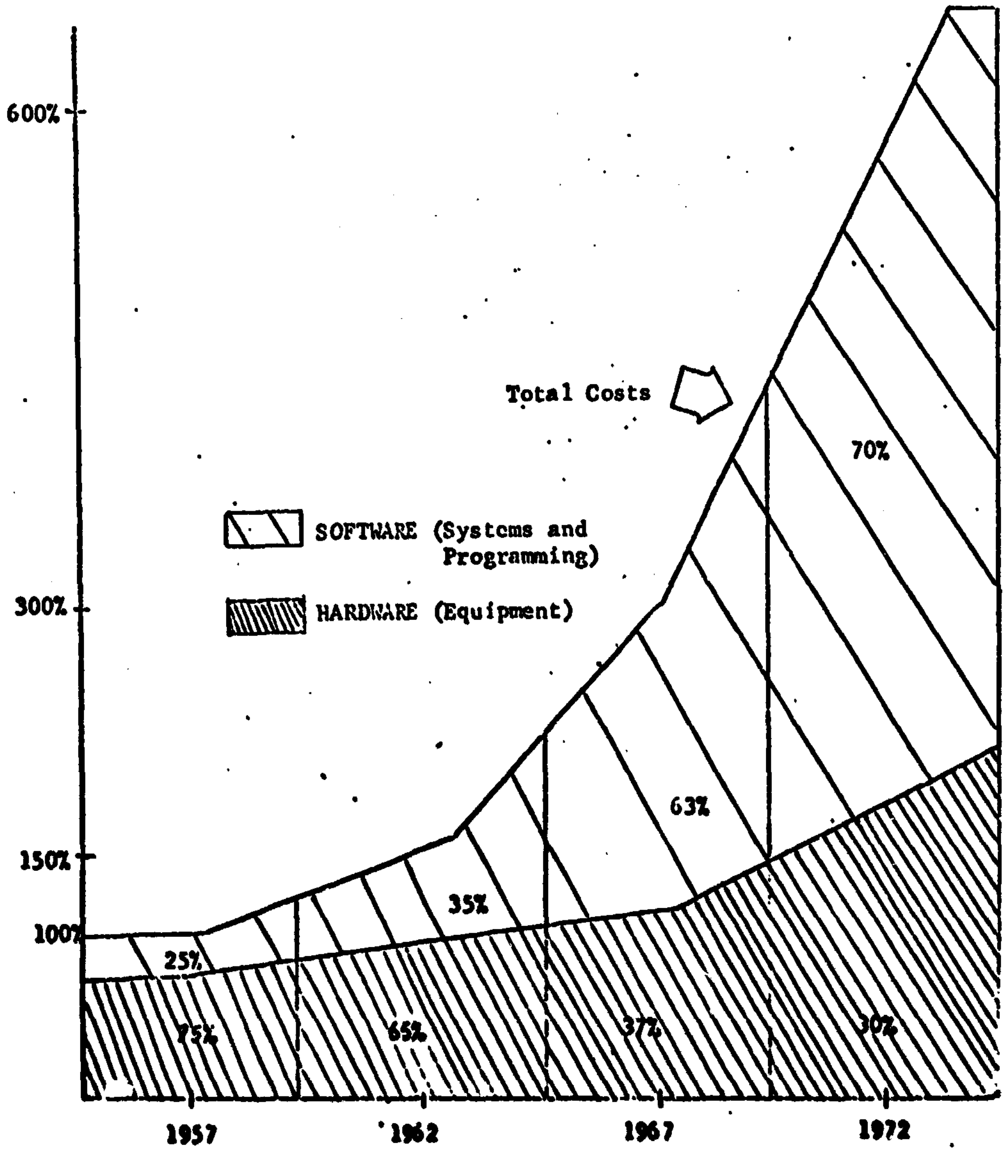
REPRESENTATIVE COMMERCIAL PACKAGES OF SIMULATORS
FOR COMPUTER SYSTEM EVALUATION

PROGRAM:	CASE	SAM	SCERT
NAME:	Computer-Aided System Evaluation	System Analysis Machine	System and Computer Evaluation and Review Technique
COMPANY:	Computer Learning and Systems Corp. 5530 Wisconsin Ave. Chevy Chase, Md. 20015	Applied Data Research Route 206 Center Princeton, N.J. 08540	Comress 2 Research Court Rockville, Md. 20850
COSTS:			
Purchase	$50,000	Not for sale	Not for sale
Lease (Monthly)	$3,000 (1 yr.min.)	$3,500 (3 mo.min.)	$1,000-3,000 (1 yr.min.)
Single study	$4,000 and up	$5,000 and up	$5,000 and up
Analyst support	$250/day	$250/day (after 10 days)	$250/day
EDUCATION:	$1,000 for 10 man-days (includes 10 man-days of analyst support)	5 man-days free	$500 for 10 man-days
SYSTEM:			
Available on	360/50, GE 600, CDC 6000,	360/50	360/40 (and up), Univac 1108
Core needed	200K	225K	110K
Written in	Fortran	Fortran	Assembler
DATE AVAILABLE:	1969	To be released	1964

decision" by the key manufacturers last year to price hardware and software separately appeared at first glance to simplify some of these issues, the software marketplace is still a morass of confusion. For example, during the past few years a major consideration in software design and development for MIS has been the appearance of "data (file) management systems" or "generalized data base management systems"; e.g., Byrnes and Steig (1969), and Fry and Gosden (1969). In broad terms, data management software is intended to de-couple the user from the technical details of the hardware in interfacing with a data bank; as such, it may be characterized as an extension of programming language capability for data manipulation. Today, however, there are more than fifty such software systems commercially available (cf., CODASYL, May 1969) to the bewildered customer, each offering a variety of features and approaches to data management, with relatively little hope (cf. CODASYL, October 1969) for commonality or standards in the foreseeable future.

Figure 2

TREND COMPARISON OF COMPUTER SYSTEM
COST DISTRIBUTION IN TYPICAL COMPANY



Beyond specific software technology, trends over the past decade strongly indicate that the largest cost element of systems is "people." Figure 2 summarizes the proportionate cost distribution since 1957 and projects the likely ratio for 1972. While relative costs are fairly easy to extrapolate it is clear from industrial experience that cost estimates for application projects, particularly personnel cost estimates, are usually poor and biased downwards. (e.g., see Laska (1970) for some unfortunate case histories). Thus, one concludes that the state-of-the-art in evaluating system technology today is still very subjective and to some degree the dark art of "magic". As a science there is much need for empirical research -- for those interested in more extensive bibliographies see Buchholz (1969) and the Metametrics Corporation (1969), as well as earlier citations. Rather than despair the issue entirely, it might be argued with caution that technological evaluation is not the crux of the problem in MIS. Indeed the management potential of a particular system application may provide benefits of a magnitude that overwhelm the need for a detailed appraisal of technological costs. Why sub-optimize the technological design when the primary considerations in MIS are management opportunities?

4. MIS Evaluation: The State-of-the Art

Parhaps the most important lesson of the past decade in the field of MIS has been the maxim that the relative success of a system application is a direct function of the participation by management in its design and development. McKinsey (1968) recently summarized this fact in an international survey of industrial corporations, by noting three dimensions of management system performance: technical feasibility, economic feasibility and operational feasibility. The third dimension, conspicuously absent in system failures, roughly translates into the requirement that the developed system be understood and used by managers. Given that a system (application) has successfully met the tests of technical and economic feasibility, "will managers adapt to the system, or will they resist or ignore it?" By analogy with Professor Churchman's (1968) perspective on "systems analysis," the principals involved in design and development, technicians and managers, must be sensitive to each other's value system -- they should try to see the world through one another's eyes. Having acquired this "sensitivity," they should put their relative expertise in perspective.

Within a large organization computer and data processing staff can be expected to possess a reasonable degree of technical competence, given educational and experience credentials. Staff technicians, however, rarely possess the broad guage focus of line management in understanding the economic and environmental factors critical for the particular organization's successful enterprise.

One approach to the goals and criterion problem is to seek a general strategy statement from management for information systems design and development, e.g., Kriebel (1968). Another technique, that has received acceptance in a variety of forms, is illustrated by the so-called "Study Organization Plan (SOP)" of IBM (1963). In brief SOP approaches a systems study in three phases: (1) understanding the present business, (2) determining system requirements, and (3) designing the new system. The first phase of the study seeks a detailed description of the "present business" through an economic analysis which includes: history and framework, industry background, firm goals and objectives, firm policies and practices, government regulations, products and markets, materials and suppliers, and resources (facilities, personnel, inventory, and financial). This description is then summarized into a list of "activities" which are costed. Phase 2 of SOP analyzes the goals and objectives, economics, and procedure of execution for each activity in terms of input-output requirements in operational detail. The final phase of SOP develops specific recommendations and plans for introducing a new business system. IBM gives five criteria for choosing activities as automatic data processing candidates, viz.: (1) Dominant performance criteria (e.g., response time to customer inquiry). (2) High affectable dollar savings. (3) Large data processing size (e.g., volumes). (4) Inefficiencies. (5) Management preference. The "technique" includes some well-designed forms to assist conduct of the study at each phase, and although the ideas are not "new" the logic is well-founded and useful in practice.

In the absence of a direct policy statement by management or an extensive economic analysis of "the business", perhaps the most important index of the relative worth of a system application is the criticality of the activity to the organization. Sometimes the index can be measured directly, e.g., cost savings or profitability; however, often it is a function of surrogate measures. The role of surrogates as proximate criteria of performance may often be the only alternative available to the designer, particularly, if the system application is not directly tied to a management activity -- e.g., file maintenance. Surrogate criteria can also serve in performing a "dominance analysis" of the attributes or properties of design alternatives, in lieu of a uni-dimensional objective function. For example, the development of proximate criteria can serve to establish bounds and constraints on the search for design alternatives in much the same manner as a consumer product testing organization's report of "best buys" for household items. In this regard the decision theory criterion may provide a useful guideline for directing search.

It is clear today that the magnitude of the problem of MIS evaluation is going to grow during the next decade and beyond. In the late 1950's and early 1960's clerical displacement, cost reduction and control of administrative expense were the primary criteria applied to management data processing system proposals. The direction and scope of MIS has long since left the domain of administrative and accounting applications. Last year Diebold (1969) projected a time frame for applications and evaluation criteria over the next 15 years. These forecasts are summarized in Table 3. Referring to the criteria column in the table, it is clear that during the next decade management and policy makers are going to face some serious questions if these projections are to materialize by applications area.

Table 3
PROJECTION OF CRITERIA USED IN EVALUATION OF MIS
(Diebold, 1969)

DATE	SYSTEM GENERATION	MANAGEMENT APPLICATION	EVALUATION CRITERIA
1964	Second	Administration and Accounting	Clerical Displacement; cost reduction; control
1968	Third	Supervisory Information	Reduction in inventories; reduction in cash balance; personnel stability; customer relations; vendor/buyer relations; cost control
1975	Third + and Fourth	Middle Management and Tactical Planning	Optimum marketing budget; return on short-term portfolios; improved negotiating position; improved vendor performance; optimum use of plant; improved shipping schedules; more realism in forecasting
1985	Fifth	Top management and Strategic Planning	Product planning; capital requirements; labor and materials planning; resource planning; transportation and inventory planning.

5. Conclusions

The development of management information systems has come a long way in the last ten years, heralded much by advances in technology. The computer, however, has been an expensive "fad" in companies where management has not taken the time to become involved in the process of MIS design. The milestone called "evaluation" is the most conspicuous and weakest stage in this process today. The techniques available and those employed for evaluation need much improvement. Perhaps as responses to this need for the short run are two industry trends. The first trend in evidence is the emergence within large corporations of the computer/information systems department as a "profit center" -- in some cases incorporated as a subsidiary, selling services to outside customers, as well. The second development is the appearance of software companies with the facilities to sell an MIS package (not limited to data management software) to a customer organization. The vendor in this case contracts a fixed-price-plus-maintenance agreement for design, development, implementation, and in some cases continuing operation (i.e., on the vendor's equipment or under an installation management arrangement). I think both trends are in the right direction, but represent only an interim solution to the evaluation issue. The time when a large computer installation is "justified" on the basis on intangibles alone is passed. There will be increasing pressure to evaluate MIS proposals on their economic potential -- though <u>not</u> on administrative cost reduction, as in the past. However, the economics of upper management decision processes, are not straight-forward or well understood, and many questions need to be answered. For example, what economic and behavioral issues should be detailed for an MIS in support of strategic planning? It is clear to me that many of the answers must come from the executives involved.

As a professional I am concerned about this major gap in the state-of-the-art of MIS, particularly when I see and feel the push of technology which says: Move! I suggest we all have much in common with the Red Queen's observation to Alice:

> "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run twice as fast as that"
> -(Through the Looking Glass).

I urge that we try to run twice as fast as we have, not in developing the brute force technology, but in deciding what we want the technology to do.

6. References

R. A. Arbuckle, "Computer Analysis and Thruput Evaluation," Computers and Automation (January 1966), p. 13.

J. N. Bairstow, "A Review of Systems Evaluation Packages," Computer Decisions (June 1970), p. 20.

J. Becker and R. M. Hayes, Information Storage and Retrieval: Tools, Elements, Theories (John Wiley and Sons, 1963).

B. F. Boyd and H. S. Krasnow, "Economic Evaluation of Management Information Systems," IBM Systems Journal (March 1963), p. 2-23.

A. C. Bromley,"Choosing a Set of Computers," Datamation (August 1965), p. 37-40.

W. Buchholz, "A Selected Bibliography on Computer System Performance Evaluation," Computer Group News I.E.E.E. (March 1969), p. 21-22.

C. J. Byrnes and D. B. Steig, "File Management Systems: A Current Summary," Datamation (November 1969), p. 138-142.

P. Calingaert, "System Performance Evaluation: Survey and Appraisal," Communications of the ACM (January 1967), p. 12-18.

C. West Churchman, The Systems Approach (Delacorte Press, 1968).

CODASYL Systems Committee, "A Survey of Generalized Data Base Management Systems" (May 1969), Association for Computing Machinery, New York City.

CODASYL Data Base Task Group, "October 1969 Report", Association for Computing Machinery, New York City.

John Diebold, "Bad Decisions on Computer Use," Harvard Business Review (January-February 1969), p. 14-16 ff.

J. Fry and J. Gosden, "Survey of Management Information Systems and Their Languages," p. 41-56 in F. Gruenberger (ed.), Critical Factors in Data Management (Prentice-Hall, 1969).

R. V. L. Hartley, "Transmission of Information," Bell System Technical Journal, Vol. 7 (1928), p. 535-563.

P. B. Henderson, Jr., "A Theory of Data Systems for Economic Decisions," unpublished Ph.D. Thesis, Economics Department, M.I.T., Cambridge, Mass. (June 1960).

D. J. Herman and F. C. Ihrer, "The Use of a Computer to Evaluate Computers," Proceedings AFIPS 1964 Spring Joint Computer Conference, Vol. 25, (April 1964), p. 383-395.

John R. Hillegass, "Standardized Benchmark Problems Measure Computer Performance," Computers and Automation (January 1966), p. 16-19.

IBM Corp. (1963). Publications on "Study Organization Plan" (SOP): The Approach, F 20-8135; Documentation Techniques, C20-8075-0; The Method Phase I, F20-8036-0; The Method Phase II, F20-8137; The Method Phase III, F20-8138-0.

IBM: "Systems 360 Model 67 Time-Sharing System Technical Summary" (August 18, 1965).

K. E. Knight, "A Study of Technological Innovation -- The Evolution of Digital Computers," unpublished Ph.D. Thesis, Graduate School of Industrial Administration, Carnegie-Mellon University (November 1963).

C. H. Kriebel, "Operations Research in the Design of Management Information Systems," Chapter 22, 375-390 in J. F. Pierce (ed.), Operations Research and the Design of Management Information Systems (Technical Association of the Pulp and Paper Industry, 1967).

C. H. Kriebel, "The Strategic Dimension of Computer Systems Planning," Long Range Planning (September 1968), p. 7-12.

C. H. Kriebel, J. T. Heames, and R. L. Van Horn (ed.), Management Information Systems: Progress and Perspectives (Carnegie-Mellon University, 1970).

R. M. Laska, "Keeping Your Computer Out of the Till", Computer Decisions (May 1970), p. 19-23.

Jacob Marschak, "Elements for a Theory of Teams," Management Science (January 1955), p. 127-137.

J. Marschak, "Economics of Inquiring, Communicating, Deciding," American Economic Review (May 1968), p. 1-18.

McKinsey and Company, Inc., Unlocking the Computer's Profit Potential (New York City, 1968); reprinted in Computers and Automation (April 1969), p. 24-33.

"Computer Evaluation and Selection: A Bibliography," prepared for the Association for Computing Machinery by Metametrics Corporation (1969); ACM Professional Development Seminar. (61 entries).

H. Raiffa, Decision Analysis (Addison-Wesley, 1968).

Roy Radner, "Team Decision Problems," Annals of Mathematical Statistics (September 1962), p. 857-881.

N. F. Schneidewind, "Analytical Model for the Design and Selection of Electronic Digital Computers," Unpublished D.B.A. Thesis, Graduate School of Business, University of Southern California (January 1966).

C. E. Shannon and W. Weaver, The Mathematical Theory of Communication (University of Illinois Press, 1948).

William F. Sharpe, The Economics of Computers (Columbia University Press, 1969).

H. A. Simon, The Sciences of the Artificial (MIT Press, 1969).

M. B. Solomon, Jr., "Economies of Scale and the IBM System/360," Communications of the ACM (June 1966), p. 435-440.