

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-667

A Contemporary View of Systems Engineering

Ralph F. Miles, Jr.

(NASA-CF-136833) A CONTEMPORARY VIEW OF
SYSTEMS ENGINEERING (Jet Propulsion Lab.)
23 p HC \$4.25 CSDL 12B

N74-17667

Unclas
G3/34 30003

**JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA**

January 15, 1974

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-667

A Contemporary View of Systems Engineering

Ralph F. Miles, Jr.

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 15, 1974

PREFACE

The work described in this report was performed by the Mariner Jupiter/Saturn 1977 Project.

Thirty years of applying the systems approach have given us some understanding of its capabilities and limitations.

This report is based on a lecture series sponsored by the California Institute of Technology and published in SYSTEMS CONCEPTS: LECTURES ON CONTEMPORARY APPROACHES TO SYSTEMS, Edited by Ralph F. Miles, Jr., John Wiley and Sons, Inc., 1973.

PRECEDING PAGE BLANK NOT FILMED

CONTENTS

	Page
Introduction	1
The Definition of a System	1
Systems Engineering with the Systems Approach	4
Statement	5
Synthesis	5
Analysis	6
Selection	7
Implementation	8
Four Contemporary Systems	9
Example #1: Aerospace Programs	9
Example #2: An Operations Research Project	11
Example #3: The Planning-Programming-Budgeting System	14
Example #4: An Information Processing System	16
Conclusion	17

PRECEDING PAGE BLANK NOT ~~FILMED~~

"A Contemporary View of Systems Engineering"

by Ralph F. Miles, Jr.

ABSTRACT

This article defines the concept of a "system," discusses the "systems approach," and presents four contemporary examples of the systems approach. It is a condensation and summary of a 1971 lecture series sponsored by the California Institute of Technology and published in Systems Concepts: Lectures on Contemporary Approaches to Systems, edited by Ralph F. Miles, Jr., John Wiley, 1973.

Introduction

While the exact origins of systems engineering as a discipline are somewhat obscure, at least three distinct activities contributed to its initial conceptual development. In the years just prior to World War II, companies in the communications industry, such as the Bell Telephone Laboratories and the Radio Corporation of America, recognized that the proper design and operation of telephone and television services would require that these services be considered as total systems rather than as assemblages of components. During World War II, scientists working on the problems of war operations developed the methodology of what came to be known as Operations Research. By the end of World War II, the Armed Forces realized that the increasing technical complexity of military equipment would require new approaches to their management, design, and operation. Since that time, systems engineering has become the sine qua non for the development of all military, communication, and aerospace systems.

The Definition of a System

Most definitions of "system" include the concept of a collection of elements and a set of interrelationships between the elements. To the extent that the definition focuses on the totality of the interrelationships and not on the elements per se, "system" is synonymous with the psychologist's "gestalt," and emphasizes the idea that a system is a conceptual entity apart from the mere summation of its elements.

Systems engineering is primarily concerned with the creation and operation of systems. The main theme of systems engineering is that the system exists for a purpose, and that the elements of the system are created and interrelated as a means of achieving this purpose. Within this context a more restrictive definition of "system" is appropriate.

"A system is a set of interrelated elements which function for a purpose."

Even this definition is somewhat too general, for systems engineering is hardly appropriate to, for example, a respiratory system or an automobile ignition system. Thus other restrictions need to be invoked in order to limit the class of systems to be considered. Robert Machol, Professor of Systems at Northwestern University, considers systems relevant to systems engineering to have some, but not necessarily all, of the following properties:

- * The system is man-made.
- * The system has integrity--all components contribute to a common purpose, the production of a set of optimum outputs from the given inputs.
- * The system is large--in number of different parts, in replication of identical parts, perhaps in functions performed, and certainly in cost.
- * The system is complex, which means that a change in one variable will affect many other variables in the system, rarely in a simple manner.
- * The system is semiautomatic with a man-machine interface, which means that machines always perform some of the functions of the system and human beings always perform other functions.
- * Some of the system inputs are random, which leads to an inability to predict the exact performance of the system at any instant.

There is no generally accepted definition which will separate systems from nonsystems. A system, much like beauty, lies in the eye of the beholder. A decade ago, the title of "system," within the context presented here, was usually construed to apply only to technical systems, but today the term has been extended to civil and social systems. Simon Ramo, Vice Chairman of the

Board and Chairman of the Executive Committee of TRW Inc., argues that a city is a system, whether or not we choose to regard it in that light. He says if we choose not to, then it will simply be a bad system.

It is now common to make a distinction between technical systems and civil or social systems. While the distinction is by no means clear-cut, technical systems tend to be more related to hardware elements and to have objectives related to the performance of the hardware elements. Robert Boguslaw, Professor of Sociology at Washington University, defines a social system not in terms of the relative proportion or roles played by humans in the system, but in the degree to which the system objectives are related to social welfare. In this hierarchy of definitions, civil systems would lie somewhere between technical and social systems.

The difficulties of precisely defining a system, the system boundaries, and the system objectives--even for a technical system--can best be illustrated by the following example. A Boeing 747 jet airplane may be considered to be a technical subsystem of a transportation system. The complete transportation system must also include the personnel--pilots, stewardesses, ground crews. There must also be a reservation system, airports, communications, navigational aids, and an air traffic control system.

In addition to the organizations required to manage and operate these systems, there must also be other organizations concerned with the overall resources invested and the overall return obtained. At one level this involves the stockholders and the management of the airline. At a higher level it involves the national government or a consortium of governments. It is they who must provide the overall objectives and decision criteria for the system and make the difficult trade-offs between public and private investment, convenience versus efficiency of operation, user versus nonuser considerations, and profit versus safety and reliability.

Thus what started off to be a straightforward technical system with seemingly well defined interfaces, on closer inspection becomes a subsystem threaded through many larger systems, with system objectives so complex that there are limited prospects of realizing complete answers to questions as fundamental as, "Do the benefits equal the resources expended?"

Systems Engineering with the Systems Approach

Systems have been engineered in one fashion or another for millennia. Systems engineering today represents more of a change in emphasis than a change in content--more emphasis on defining goals and relating systems performance to these goals, more emphasis on decision criteria, on developing alternatives, on modeling systems for analysis, and on controlling implementation and operation.

Systems engineering focuses on achieving objectives, and it attempts to achieve these objectives through a logical, structured approach called the "systems approach." The systems approach brings together the rigorous thinking of science and a number of common-sense ideas related to problem-solving and design. The systems approach starts with the notion of a system composed of a number of elements which function in an interrelated manner. The system is viewed as existing in an environment uncontrolled by the system, but which nevertheless influences its behavior. Invariably, the system itself can be viewed as an element of some larger system.

The system is considered to have a goal or objectives, and the system is optimized at the system level to achieve these objectives. The functions assigned to the various system elements and the selection and operation of the system elements should reflect this philosophy of system optimization. This may well mean that some elements of the system are operated in other than their most efficient manner.

The systems approach assumes that alternatives potentially exist for the system. These alternatives must be developed, they must be understood, and

that system alternative should be selected which "best" satisfies the objectives of the system.

Finally, the systems approach advocates a logical approach to thinking about the system. The methodologies and philosophy of science are to be used in formulating the system objectives, in the development and analysis of alternatives, and in the process by which the system alternative is selected and implemented. This implies an intellectual precision not normally associated with "nonscientific" enterprises.

The systems approach is an extension of problem-solving methods of the kind that John Dewey posed when he asked, "What is the problem? What are the alternatives? Which alternative is best?" This theme is present in the steps to the systems approach, which are typically presented as:

1. Statement of system objectives.
2. Synthesis of alternative systems.
3. Analysis of alternative systems.
4. Selection from the alternative systems.
5. Implementation of the selected system.

Statement. The first step of the systems approach--to state the system objectives--is not at all an easy one. Even though the system objectives may have been derived from broadly relevant goals, they nevertheless must be stated in sufficient detail so as to permit evaluation and selection between system alternatives. The most important systems--the very large ones--must somehow relate to national goals, which are often elusive and controversial. The formulation of the system objectives deserves an analysis in and of itself. For the system objectives, implicitly if not explicitly, determine the boundaries of the system, the range of system alternatives potentially admissible, and the criteria of optimality to be used in all the analyses that follow.

Synthesis. The second step is a creative process: To synthesize system alternatives--not just one, but a range of alternatives--from which a selection

can be made. It is possible to devise new system alternatives by analyzing existing systems. New combinations of the elements of existing systems may yield potential alternatives. Beyond this, no technique presently exists for the creation of totally new alternatives. It is unfortunate that this step, which embodies the essence of invention, is so little understood and that so little can be said about it.

Clearly the systems approach, when applied to a set of poor alternatives, no matter how sophisticated and clever the analysis, can only yield a poor solution. Henry Rowen, Professor of Public Management at Stanford University and former President of The Rand Corporation, makes the point that many problems appear, and are, intractable if viewed statically. But new inventions, both technical and social, can make a difference. They introduce a new set of alternatives which may help--not necessarily by providing complete solutions, for new inventions create new problems, but by ameliorating and resolving old problems.

Analysis. The third step involves analysis. Given the system alternatives and given the stated objectives, develop an understanding of the alternatives and the degree to which they satisfy the objectives. The preponderance of literature which exists on systems engineering is primarily concerned with this step and the appropriate analysis techniques. These analysis techniques can be applied, in very sophisticated ways, whenever the system objectives and the system parameters can be quantified.

For this systems analysis, in addition to the classical mathematical methods, techniques have been developed specifically for large scale systems. Queuing theory and systems simulation techniques have been developed by the M.I.T. Operations Research Center under the leadership of Philip Morse. The "simplex" method for the solution of linear programming problems was developed by George Dantzig and his associates for modeling resource allocation problems for the U.S. Air Force. Dynamic programming was originally developed by Richard Bellman in the early 1950's at RAND as a tool for analyzing multistage

decision processes. PERT (Program Evaluation and Review Technique) was developed by the U.S. Navy as a technique for preparing program schedules, and for assessing the progress of the program with respect to the schedules.

Unfortunately it is not always possible to quantify the system objectives and the system parameters, and in fact for the most important systems it is never possible to quantify all the objectives. In spite of this obstacle--the apparently nonquantifiable nature of the total system--analysis to the extent it can be accomplished is nearly always beneficial. At least it will indicate the preferred alternatives if the decision maker were to consider only the quantifiable aspects.

Selection. The fourth step is selection. The results of the analysis are used to determine which alternative is "best" in terms of the criteria the systems designer has selected to represent the overall measure of optimality of the system. Because the analysis is incomplete in that it rarely includes all the considerations, the decision maker must use his subjective judgment in assessing the relative importance of the nonquantifiable aspects of the decision in the selection of the "best" system.

To the extent that the decision can be quantified, the techniques of "decision analysis" can be used to select between system alternatives. Decision analysis identifies the optimum alternative by combining the systems analysis of the preceding step with the value structure, risk preference, and time preference of the decision maker. Decision analysis also provides a means of communication that aids the separation of issues from nonissues (through the use of systems models to identify and structure the relevant parts of the decision), facts from fiction (through the use of probability theory to encode uncertainty), and value judgment from technical description (through the use of utility theory to encode values).

Two studies performed recently by Ronald Howard of Stanford University and James Matheson and his associates at the Stanford Research Institute

illustrate the magnitude of complexity and uncertainty that can be addressed with decision analysis. The first study was undertaken for the Mexican government and concerned the future expansion of the Mexican electrical power system. The study specifically addressed the question of whether nuclear power plants should be installed in Mexico and, if so, how they should be phased into the electrical system, and how they should be operated and priced. Since any decision of this magnitude would obviously affect the entire Mexican economy, it was necessary to develop a comprehensive model including not only the outputs that would appear on the balance sheet of a corporation, but also social outputs such as the benefits to Mexican industry, the creation of new public works, the dependence on foreign supply, and the environmental implications.

The second study was undertaken for the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, and focused on the decision problems inherent in hurricane modification by seeding with silver iodide. The study addressed the policy decision concerning the present prohibition against seeding hurricanes threatening coastal areas. It also examined the value of expanding research in hurricane modification.

Implementation. The fifth and last step is implementation, in which the selected system is brought into being. This final step is the critical step, in that the foregoing steps are only an intellectual exercise unless this final step can be realized. C. West Churchman, Professor of Business Administration at the University of California, Berkeley, says that with respect to the design of organizations, implementation is the most important and difficult step--that what has come before is minor compared to the problem of changing an organization in the light of analysis.

Although the steps to the systems approach appear in a logical progression, it should not be inferred that these steps occur this simply in practice. There is a paradox in the design of large systems. The requirements for a large system can never be fully understood until the system has been completely designed, yet the system cannot be completely designed until the requirements

are fully understood. Thus the design of a large system is extremely iterative, with the systems design proceeding from requirements to systems to requirements and so on, with each iteration in principle producing a more optimized and detailed design.

Four Contemporary Systems

With this discussion of "systems" and the "systems approach," four contemporary systems will now be examined to understand how the systems approach was applied and what success resulted. These systems illustrate the systems approach in that they are goal-oriented (designed to meet stated requirements), three of the four examples explicitly display the steps to the systems approach, and all of them represent systems optimized at the systems level.

Example #1: Aerospace Programs

Aerospace programs represent the pinnacle of achievement for the systems engineering of technical systems. For these programs, the systems approach is evident in the chronological phases of definition, design, implementation, and operation. The definition phase involves an analysis of the requirements and selection criteria, a generation at the systems level of a range of feasible alternatives, and an analysis of the best alternatives. The conclusion of the definition phase comes with the selection of one systems alternative, and with a gross understanding of the implications of the selected alternative with respect to performance, cost, schedule, risk, required technology development, system lifetime, and interfaces with other systems.

The design phase starts with the product of the definition phase, a grossly defined system, and proceeds to define, design, and analyze the system down to the level such that all documentation exists for the complete creation of the system. The implementation phase brings the system into being. This phase includes the procurement of parts and materials, fabrication and assembly of hardware, coding and validation of computer software, and training of personnel.

The implementation phase ends with the system level tests or review processes which are required to certify the system for operation. The operations phase starts with the first application of the system to its stated purpose and continues through to the final phase-out of the system at the end of the life-cycle.

For the purposes of both management and engineering control, these programs are divided into major systems, the systems into subsystems, and so forth. The successful Mariner Projects, managed by the Jet Propulsion Laboratory for NASA, have typically been divided into four or five major systems. A "matrix" organization structure is often used to focus and integrate these management and engineering efforts. The classical organization chart with vertically aligned functional divisions is overlaid with horizontally aligned programs which intersect the division structure.

Most of these aerospace programs function in an environment of organizational elements partially dedicated to other programs, and with systems which compete for the program resources. Thus a program office is required for these programs to exist as viable and recognizable entities, and for the optimization process to occur at the program level. A program manager is assigned to provide a management interface with the higher-level organizations, to provide direction to the program systems and to the committed organizational elements, to assess the current program status, and to determine the degree to which the program objectives are consistent with the program resources. The program manager has a staff which carries out the management of the program resources, which participates in the trade-off decisions between competing or conflicting requirements of the program systems, and which performs the analyses of the program status with respect to the scheduled milestones, the performance and reliability estimates, and the present costs incurred and future costs predicted out to the program completion.

Where these aerospace programs have been successful, they have succeeded because the necessary technology existed or could be brought into being, the

design was well thought out and had been extensively analyzed, the required reliability was obtained through meticulous attention to detail and thorough testing, and sufficient visibility was attained to allow the program management to make the necessary decisions and to implement corrective action when problems were encountered.

In addition, those programs which were highly innovative required a fair measure of good fortune to succeed. George Mueller, Associate Administrator for Manned Space Flight for NASA from 1963 through 1969, lists a number of problem areas on the Apollo Program where the required technology was undeveloped or the risks were unknown: space radiation hazards, meteoroid hazards, the unknown lunar surface environment, the design of large launch vehicles, and the techniques for orbital rendezvous. The success of Apollo depended critically on the appropriate resolution of every one of these problem areas.

Example #2: An Operations Research Project

Operations Research is an experimental and applied science devoted to observing, understanding, and predicting the behavior of purposeful man-machine systems. C. West Churchman and his associates have proposed the following definition: "Operations Research is the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to the problems." The essential aspects of Operations Research are its system or organization orientation, the use of interdisciplinary teams, and its scientific approach to the solution of problems. Over the past thirty years, the methods of Operations Research have been applied to a wide range of systems problems in industrial, military, and government organizations.

The stages of an Operations Research project parallel the stages of the systems approach:

1. Formulating the problem.
2. Constructing the model.

3. Deriving a solution.
4. Testing the model and evaluating the solution.
5. Implementing and maintaining the solution.

A recent Operations Research project was undertaken by John Jennings and the M.I.T. Operations Research Center to improve the blood bank inventory system for hospitals in the Boston area. The following description illustrates each of the stages of an Operations Research project.

FORMULATING THE PROBLEM. Whole blood cannot be kept longer than 28 days; after that time it must be processed into its various components. Here a balance must be made between the chance of not having blood of a given type on hand (shortage probability) and the chance of having the blood become useless because it is too old (outdating probability) while some other hospital is short of the same blood.

Most of the major hospitals in the Boston area collected about one-half of the blood supply they used, and stored it themselves. Since the smaller the system the larger the relative fluctuations, this arrangement produced frequent glut and famine. Often one hospital would be out of blood of one type while others had to outdate some of their supply. Clearly a more unified organization could reduce outdating as well as shortages. The crucial questions were: what would it cost, what sort of operating rules were required, and how much would be the expected reduction in outdating and shortage?

CONSTRUCTING THE MODEL. The Massachusetts Red Cross Blood Center was the organization with the potential for setting up the cooperative system. It was already supplying nearly one-half of the whole blood used by the hospitals and, with its bloodmobiles, it could handle the necessary transportation as well as the central storage required by a unified system.

The first task was to gather data on average use, statistics of fluctuations, present rules of operation, and opinions of the various operating personnel. On the basis of these data and mathematical models from queuing

theory, a computer program was constructed to simulate a central bank plus cooperating hospitals, each with its own inventory. The simulation program included the fluctuations above and below each hospital's estimate of the next week's demand, delays and costs of transporting blood between hospitals or from the Center, as well as the flexibility to try out various rules of operation.

DERIVING A SOLUTION. Several different sets of rules were tried out: daily or weekly readjustment of all stocks, or a system whereby stocks of different ages would be kept at predetermined levels, with replenishment shipments provided on request from the Center or from other hospitals with oversupplies of older blood. The simulation soon demonstrated that daily readjustment involved excessive transportation costs and weekly readjustment did not sufficiently reduce outdating and shortages. The more flexible system of replenishment-as-needed (according to a set of stock rules) did not cost too much for transportation and gave promise of a reduction in loss.

The individual hospital stock rules determined the balance between the probabilities of shortage and of outdating, and this balance had to be decided by a consensus of opinion of the hospital staffs. The decision was to make the chance of outdating equal the chance of shortage for each type of blood.

TESTING THE MODEL AND EVALUATING THE SOLUTION. The details of all parts of the operation had to be known--what actually happened, not what one hoped would happen--before the simulation could be trusted to give correct predictions. In the case of the blood banks, stock rules were tried out at individual hospitals to see whether those elements went as predicted, before the system as a whole was adopted. With these rules the simulation predicted that with a system of five hospitals and the Center, both outdating and shortages could be reduced to about one-half the values experienced with the system (or lack of system) then in practice.

IMPLEMENTING AND MAINTAINING THE SOLUTION. This blood bank inventory system was installed and has been in operation for several years. The

communication and clerical costs for keeping the requisite records have been reasonable, and the savings in blood predicted by the simulation have been achieved. The operation has proved to be satisfactory to all the participating organizations.

Example #3: The Planning-Programming-Budgeting System

The Planning-Programming-Budgeting System (PPBS) has been used by the Department of Defense since 1961 and was generally adopted by the federal government in 1965. PPBS is an approach to government decision making designed to make as explicit as possible the costs and consequences of major program alternatives and to encourage the use of this information systematically in the making of public policy. PPBS has its origins in engineering through the design of complex systems, in economics through the development of cost-benefit techniques of analysis, and in public administration and business through the development of program budgeting.

Its essential aspects parallel the steps of the systems approach:

- * A careful specification and a systematic analysis of the objectives.
- * A search for the relevant alternatives, the different ways of achieving the objectives.
- * An estimate of the total costs of each alternative--both direct and indirect costs, both initial costs and those to which the alternative commits future years, both dollar costs and those costs that cannot be measured in dollar terms.
- * An estimate of the effectiveness of each alternative, of how close it comes to satisfying the various objectives.
- * A comparison and analysis of the alternatives, seeking that combination of alternatives that promises the greatest effectiveness, for given resources, in achieving the objectives.

The component parts of PPBS which the government used during the late 1960's were: (1) Program structures, which display each agency's physical and financial activities according to objective or common outputs; (2) issue letters, which summarize the agency's and the Office of Management and Budget's list of major policy issues in need of analysis and evaluation during each planning and budgeting cycle, and special analytic studies, which reflect intensive analysis of these issues; (3) program memoranda, which register agency choices between alternatives and summarize relevant analysis affecting the decisions; and (4) program and financial plans, which display for the past two and for the next five years data on the financial inputs and physical outputs resulting from proposed and past commitments.

A number of problems have inhibited the application of PPBS in government agencies. The discretionary part of an agency's budget in any given year is small because prior year decisions have committed most of the resources currently available. There is also the problem of cutting back on obsolete programs that might have made sense when they were started, but long since have lost their usefulness. Another difficulty is that many public issues and programs are very hard to evaluate. There is the complicated business of estimating the costs and benefits not just in the aggregate, but to different groups and individuals. Finally, the responsible agencies frequently do not have much incentive to apply analysis techniques even when they are available. For one thing the results might be unfavorable to that agency or its programs.

In spite of these problems, significant improvements have resulted. Many agencies have undergone at least a partial reappraisal of their functions and missions. Some improvement in ways of displaying related programs in several agencies has been made. The quality, relevance, and structure of information being developed by the agencies has improved substantially, and is being used increasingly to assist decision makers. There is also a general recognition of the legitimacy and necessity of analytical arguments--that good judgment is made even better when it can be supported by good analysis.

For these reasons, at least some aspects of PPBS now appear to be a permanent part of the government decision-making process. The government will probably continue the special analytic studies, and it will retain some type of a program budget, one, for example, which could show how much health care is provided in the aggregate from all the federal agencies.

Example #4: An Information Processing System

This example concerns the Probabilistic Information Processing System (PIP) developed by Ward Edwards and his associates at The University of Michigan. PIP is a system which can be used in decision-making situations where a large amount of inconclusive data is present. This could involve a military or political strategist interpreting intelligence data, a medical diagnosis, or even forecasting weather. PIP is especially appropriate where the situation is of sufficient complexity that a computer model of the data generating process cannot be developed, yet the data are too voluminous and inconclusive to be easily assimilated by a man.

PIP uses men and computers in a novel way to perform diagnostic information processing. PIP allows experts to judge the diagnostic implications of a single datum, something that men do quite well. The individual diagnoses are then aggregated in a computer by means of a formal rule of probability theory known as Bayes's Theorem. Bayes's Theorem, in an appropriate form, says that the odds that some hypothesis is true based on a single datum is:

$$\left\{ \begin{array}{c} \text{Posterior} \\ \text{Odds} \end{array} \right\} = \left\{ \begin{array}{c} \text{Likelihood} \\ \text{Ratio} \end{array} \right\} \bullet \left\{ \begin{array}{c} \text{Prior} \\ \text{Odds} \end{array} \right\}$$

where the "prior odds" are the odds before the datum is considered; the "posterior odds" are the odds after the datum has been considered; and the "likelihood ratio" is the probability that the datum would be observed given that the hypothesis is true, divided by the probability that the datum would be observed given that the hypothesis is not true.

In PIP, men estimate likelihood ratios for each datum and each hypothesis under consideration. A computer aggregates these estimates by means of Bayes's Theorem into posterior odds that reflect the impact of all available data on all hypotheses being considered. Such a system circumvents human conservatism in information processing, the inability of men to aggregate information in such a way as to modify their opinions as much as the available data justify. It also fragments the job of evaluating diagnostic information into small separable tasks. The posterior odds that are a PIP's output may be used as a guide to human decision-making or may be combined with a payoff matrix to make decisions by means of some rule for maximizing expected value.

PIP illustrates the concept of optimizing a system by using the system components--in this case men and computers--in the most effective manner to perform the system tasks. PIP has been used to predict the length of a stay in a hospital after an operation, to diagnose thyroid diseases, to predict recidivism in juvenile delinquents, and in retrospect to reprocess data from the Cuban missile crisis and the Chinese intervention after the Inchon Landing in North Korea. In all of these cases, PIP appears to be an improvement over systems which require man to aggregate the data, in that PIP requires less data to perform an equivalent diagnosis.

Conclusion

These four systems illustrate the systems approach as it is applied to the design of systems today. That it can work very well is both a source of satisfaction and a source of frustration. The systems approach is a source of satisfaction as an intellectual achievement in that we appear to possess the managerial and engineering ability to accomplish any task, however large, which is technically feasible. The systems approach is also a source of frustration (If we can send a man to the moon, why can't we ...?), in that our ability to accomplish these incredible technical feats seems inconsistent with our inability to accomplish tasks of seemingly lesser difficulty.

William Pickering, Director of the Jet Propulsion Laboratory, California Institute of Technology, states four requirements on a project for it to be amenable to the systems approach: (1) The project objectives must be clearly defined; (2) The project constraints--this includes legal and political constraints as well as cost and schedule--must be understood; (3) The project management structure and authority must be recognized; (4) The project must be implemented by competent personnel with available technologies.

These requirements, while directly applicable to most technical systems, rarely can be satisfied in the case of social system problems. Not only is it extremely difficult to state the goals of most social systems, the techniques for understanding and analyzing the social alternatives need much further development.

Harold Brown, President of the California Institute of Technology, believes that systems engineering is a necessity for the optimal solution of today's technological problems. He warns that systems engineering by itself will not be enough to solve the far more complicated social and economic problems that advanced societies face today. Much more must be known about the components of the socioeconomic problems--the people and the human institutions--to be able to have much confidence in the results of systems engineering approaches to such problems at the present time. Thus he concludes that systems engineering today is a necessary, but not a sufficient, factor for the solutions to the current problems of society. The decisions and conclusions in nontechnological areas will have to be reached largely through the exercise of subjective judgment and experience. Nevertheless, those judgments, however experienced and able, may be made on the basis of faulty data and poor comparisons unless the facts are presented and evaluated and all alternatives exposed through the methods of systems engineering.