APPENDIX D

INTERDISCIPLINARY BARRIERS - AN IMPEDIMENT TO THE EFFECTIVE APPLICATION OF SYSTEMS ENGINEERING

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by

Ernest Harrison, Jr.

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ABSTRACT

The necessity of including information and technology from multiple disciplines when invoking the principles of systems engineering or systems analysis for the study of large scale problems is implicit and widely recognized. Interdisciplinary transfer of information and technology does not, however, occur very readily, even for system planners, because of the existence of some very real barriers. These barriers to flow of information and technology between disciplines represent one of the important difficulties associated with the application of systems analysis to many problems. The nature and characteristics of some of these barriers are enumerated and discussed in detail. A number of methodologies and techniques which have been specifically developed to aid in the transfer of technology and information across these interdisciplinary barriers is examined. These techniques and methodologies are evaluated to determine their applicability to several classes of problems involving various levels of effort.

INTERDISCIPLINARY BARRIERS - AN IMPEDIMENT TO THE EFFECTIVE APPLICATION OF SYSTEMS ENGINEERING

1. INTRODUCTION

Systems engineering has proved to be a startlingly effective tool for the accomplishment of complex, large-scale objectives in the physical sciences and engineering. Many difficult problems have yielded to solution using these techniques. Perhaps the most outstanding example of the success of this technique is the United States Space Program which had as its objective the manned exploration of the lunar surface. The success of systems engineering as a methodology for accomplishing difficult objectives has resulted in efforts to extend its use to problems of widely varying composition and scope.

Indeed, the growth (in number and subject matter) of applications of systems engineering has resulted in a certain blurring, especially to the "public-at-large," of just precisely what systems engineering is. Consequently, in order to provide a basis for discussion, it may be worthwhile to look at some of the words that various people use when discussing this area.

2. BACKGROUND

2.1. Systems Terms. First, consider the term "system." Cleland and King[1] in their textbook have defined system as "an organized or complex whole; an assemblage or combination of things or parts forming a complex or unitary whole." Baker[2] in a survey of systems and medical care quotes several other definitions of system as: "the totality of objects together with their mutual interactions," "unity consisting in mutually interacting parts," and "a recognizably delimited aggregate of dynamic elements that are in some way interconnected and interdependent and that continue to operate together according to certain laws and in such a way as to produce some characteristic total effect."

In addition, various kinds of systems have been assigned classifications; for example, a system is classified as open or closed depending upon whether material enters or leaves the system. A system is open if there is import and export with respect to the system. It is, of course, obvious that living organisms are examples of open systems. It has been pointed out[3] that most organisms are quasi-stationary open systems. For example, metabolism is essentially a process concerned with maintainence of a steady state.

2.2. Systems Engineering Terms. In defining the term systems engineering, it is perhaps first wise to recognize that there are at least two other terms which are used to denote the activities that can be described under systems engineering. They are "systems approach" and "systems analysis". In defining systems engineering, we should keep in mind that the definition applies more or less precisely to all of these related terms as well. Rabow[4] has said that the systems approach is basically the looking at a problem from the overall viewpoint and dividing it into a set of smaller problems which, when solved together, solve the original problem.

Cleland and King[5] point out that, in essence, systems analysis is a methodology for analyzing and solving problems by systematic examination and comparison of alternatives on the basis of resource cost and benefit associated with each. In such an analysis, explicit consideration is given to the uncertainties involved in decisions which will be implemented in the future. Ramo[6] has said that the systems approach, as a basic requirement, employs an interdisciplinary team representing both the technological and nontechnological aspects of the problem to be analyzed. He points out that one of the most frequent incorrect assumptions concerning the systems approach is that highly specialized, narrow-disciplined engineers who are skillful in the details of technology but with no knowledge of the people and workings of our social systems are brought in to revolutionize these systems. This misconception has as its basis the idea that there is a pure technological solution for every problem.

This concept of the systems approach, however, is completely false. In a problem involving people, it is obviously of great importance that nontechnologists, i.e., social scientists, etc. be members of the team involved in the systems analysis effort. Particularly in the definition of system requirements, the nontechnologist may have the most valuable inputs to any concerted systems engineering approach. Finally, English[7] quotes the definition of systems engineering from the Defense Department Systems Engineering Management Procedures AFSCM375-5, "Systems engineering is fundamentally concerned with deriving a coherent total system design to achieve stated objectives. No two systems are ever alike in their developmental requirements. However, there is a uniform and identifiable process for logically arriving at systems decisions regardless of system purpose, size, or complexity."

Many have asked the question as to whether systems engineering might not actually sound just like good ordinary engineering or maybe even just good common sense. There is certainly an element of truth in such a conclusion--especially when applied to small, uncomplicated systems. Dr. Simon Ramo[8] has asked if the systems approach is really "no more than just doing things right as against doing them wrong, being intelligent rather than stupid, being objective rather than irrational in approaching problems." We would again have to answer that the systems approach, in its most general sense, seeks to bring to bear on the problem every discipline and profession which possesses information or experience pertinent to the solution of the problem. This then requires the premediated use of experience and talent, as well as disciplinary tools, of all of the individuals who can contribute to a solution of the problem. The systems approach is, by definition, objective and logical. It seeks to bring to bear all facts pertinent to the solution of a problem. It is this necessity for bringing together all facts pertinent to the problem that requires a competent interdisciplinary team.

2.3. Limitations to Systems Engineering. What are the limitations to systems engineering? First, there are obviously some systems that are so big and complex that one cannot apply an overall system analysis. It is apparent, however, that benefit can still be derived by isolating portions of these large systems and working on these smaller problems with the systems engineering approach. On the other hand, some problems are sufficiently small that a full-scale systems engineering effort cannot be justified. It is, in fact, the possibility of using some elements of the systems approach on relatively small problems, as opposed to problems involving large systems such as hospitals and larger elements of the health care system, that I wish to explore. In essence, I would like to look at the level of problems which might be encountered by the individual therapist within his or her own institution and to explore the means whereby one might apply a modified systems engineering approach or at least some of the concepts of the systems approach to these problems.

It certainly isn't inconceivable that a therapist may encounter a problem in which the skills and experience of mechanical engineers, electrical engineers, materials specialists, and various medical specialists might all be required. I am well aware that many are not in a position to purchase the multidisciplinary talent that would be required to set up a systems engineering team to attack such a problem. Must we then conclude that the average individual therapist cannot avail himself of the benefits to be obtained by the application of the systems approach? Certainly, when funding is a significant problem, one cannot employ the full-scale interdisciplinary team that is characteristic of the classic systems approach. The question then is whether or not there are other available resources which might permit the acquisition of more interdisciplinary data on the problem than can be marshalled out of the individual therapist's own experience.

Actually, the presence of people is not what one is necessarily seeking in a systems effort. What is desired is the information from other disciplines that these people can bring to bear on the problem. Now if one cannot afford to bring together such a multidisciplinary team and yet the experience and information from these fields is still necessary, then one must ask the question: "How can information from these fields be obtained?" In reality, the transfer of information and technology from one discipline to another is an extremely slow and laborious process under most circumstances. Still, if information from these other disciplines is necessary to an optimal solution of the problem, then the information must be obtained if one is to maintain any semblance of using the systems approach.

3. BARRIERS TO TRANSFER OF INFORMATION AND TECHNOLOGY

3.1. General. In many problems that we encounter, pertinent technology and information are indeed in existence in the various disciplines. The difficulty is obtaining the information and applying it to the problem. Some of this diffusion of knowledge does take place under the right circumstances. But, it has been apparent for some time that the movement of technology and knowledge from the engineering and physical sciences into the medical field is a process that does not occur spontaneously. Many who have investigated the interaction between modern technology and medicine have recognized and catalogued a variety of barriers which impede this interaction.

Recognizing that there is a significant backlog of technology already developed by the physical sciences and engineering community which may have application to medicine, let's look at some of the barriers to diffusion of this knowledge from the technological community into the medical community. Then, we will consider in some detail several methodologies and techniques which have been specifically developed to aid in the transfer of technology and information across these barriers.

Assume you have a problem which requires informational or technological input from another discipline for its solution. There are at least two ways of obtaining such information or technology. First, obviously, research and development can be undertaken with an engineering and scientific team or staff to generate the new technology required. Second, advanced technology might be transferred from other fields or disciplines. The latter can be much less expensive provided: (1) the technology already exists somewhere, (2) the required technology can be identified, and (3) the technology can be transferred, that is, modified for effective utilization.

3.2. Why Transfer Is Attractive. What are the factors that make the transfer of technology and information from one field to another attractive?

(1) There has been an extremely large expenditure of funds both privately and by the government on research and development programs and application programs involving advanced technology. If multiple uses for this technology can be found, it will increase the return on the investment dollar.

(2) Because of the large amounts of money spent on advanced technology in these various programs, there is a large technology base or reservoir from which applicable technology can be sought.

(3) Advanced methods of searching for technology (e.g., computer searching of entire fields of learning very rapidly) have made the task of looking for specific problem solutions within the technology reservoir easier.

3.3 The Barriers. Some barriers to interdisciplinary information and technology transfer are given in Table 1.

Table 1 - BARRIERS TO TRANSFER

(1) Compartmentalization of knowledge and technology within discrete specialized fields.

(2) Language barriers.

(3) Size of the technology reservoir.

(4) Organizational (structural).

(5) The "not-invented-here" syndrome.

(6) Resistance to novel solutions.

(7) Alienation of administrators and scientists.

(8) Treachery of written material.

Considering these in order:

(1) Compartmentalization of knowledge and technology within discrete specialized fields. The increasing specialization of scientists and engineers has reduced the probability of contact with those outside their specific disciplines. The state-of-the-art in many specialized disciplines is advancing so rapidly that individuals frequently have no time for anything but pursuit of their own specialization. This has led to compartmentalization of knowledge and technology so that other scientists and engineers outside a

particular specialty know little about advances in technology within that specialty field. Boulding[9] calls this specialization process "specialized deafness" and defines it to mean "that someone who ought to know something that someone else knows isn't able to find it for lack of generalized ears." He points out that one of the crises of science today arises because of the increasing difficulty of profitable talk among scientists as a whole.

(2) Language barriers. Concurrent with the specialization which has taken place within the scientific and engineering disciplines has been the growth of a disciplinary jargon or specialized language which requires membership in the discipline in order to be intelligible. This results because generalized language is too unwieldy or nonspecific to permit description of the precise meanings demanded by specialization. In many cases, the new language is invented concurrently with new discoveries by specialists in their fields. Finally, most specialists interact only with peer groups, that is, they only talk to each other. Consequently, there is little impetus for the language developed within each specialty to be utilitarian in structure or to be intelligible to those outside the group.

(3) Size of the technology reservoir. There is no question that we are in the throes of an information and technological explosion. Burgeoning growth of technology and information has caused the technology reservoir to become so large that an attempt to locate a specific item of technology in this reservoir has become a formidable task. The size of the technology reservoir actually has two effects. (A) The larger the reservoir, the higher the probability that a solution exists in the reservoir. (B) By the same token, the larger the reservoir, the more difficult it is to find or identify a

solution that exists in the reservoir and, perhaps more important, the greater the difficulty of even establishing the existence of a solution.

It is this increasing amount of time and effort required to establish the existence of applicable technology within the reservoir (to search the reservoir) which has caused large numbers of people to despair of this approach and instead invest their time and funds in a development program to produce the required technology. The history of modern-day technology is replete with examples of this "re-invention of the wheel." It is certainly justifiable to "re-invent the wheel" any time that the cost of determining whether or not someone else has already invented the wheel becomes a significant portion of the investment required for re-invention.

There is, in addition, a more subtle consideration which affects the choice of whether or not to search the reservoir before undertaking to develop the required technology. Generally, applicable technology found in another field must be modified (re-engineered) to permit it to function effectively under the constraints of use in the new discipline. This re-engineering must be done, and someone must pay for it. The cost of re-engineering varies over a rather wide range depending upon the degree to which the capabilities of the technology match the requirements of the intended application. The net result of these factors is that unless the problem is extremely difficult and development of the technology "from scratch" is very expensive, most people will choose to "re-invent the wheel."

(4) Organizational (structural). Sometimes the barriers to technology and information transfer are structural in nature. For example,

the experiences of industry are replete with instances of people inventing the same thing in different departments within the same organization, or perhaps even worse, of someone requiring technology which is well-known in one department but unavailable in the department which needs the technology. When departmental lines are strongly drawn with little interchange between departments, structural barriers are frequent within organizations.

(5) The "not-invented-here" syndrome. There is sometimes very powerful resistance to seeking information or technology from outside. While a seemingly foolish barrier, it is, nevertheless, a very powerful factor in many situations and sometimes completely overrides all other considerations.

(6) Resistance to novel solutions. Novel solutions are sometimes not associated with the problem for which they are a potential solution and thus difficult to recognize. In addition, there is a tendency to reject novel solutions out-of-hand. Black[10] points out that if one undertakes "an adequate, serious, open-minded analysis of an unusual approach, it is often annoying, emotionally disturbing, and hard work."

(7) Alienation of administrators and scientists. Administrators are frequently in a position to perform a coordinating function between disciplines but are sometimes prevented by hostility and friction between scientists and administrators.

(8) Treachery of written material. It has been amply illustrated that transfer of technology by means of written material is very difficult. This is a well-known and widely documented fact. Many who have attempted to obtain information or technology from a "foreign" discipline by means of written communication (for example, journal

articles) have discovered how difficult such a procedure really is. In most cases a telephone call or visit to the author is eventually required to obtain all the information needed for implementation of technology.

4. ATTEMPTS TO REDUCE THE BARRIERS

A number of techniques have been employed in an attempt to overcome these barriers. Some of these are listed in Table 2 and discussed in the following paragraphs.

Table 2 - METHODS OF REDUCING THE BARRIERS

(1) Systems Engineering Team.

(2) Multidiscipline people.

(3) People transfer.

(4) Computerized information searches.

(5) Experimental technology transfer programs.

4.1. Systems Engineering Team. The multidisciplinary systems engineering team employed in the systems approach is obviously a large-scale attempt to overcome the interdisciplinary barriers to technology transfer. It takes account of a fact, to be discussed later, that interdisciplinary barriers are rendered significantly less effective when person-to-person contact between disciplines is possible. By bringing together representatives of all of the disciplines which can contribute to a problem, communication between those individuals is greatly enhanced, resulting in transfer of information and technology between disciplines. This answer is, of course, the classic answer of systems engineering.

4.2. Multidiscipline People. There has been a relatively new development, within the past 10 to 20 years, which has as its objective the bridging of the gap between disciplines; namely, the training within our universities of multidiscipline people. This development has occurred in a number of fields, including medicine. Examples of intermarriage of such disciplines can be readily found; for example, biochemistry, biophysics, and in more recent times we have been the development of biomedical engineers and biomechanical engieneers. These people receive training in two disciplines, usually a field of medicine and a technical specialty. The objective of this type of training is to produce an individual who can communicate with the medical field and yet can bring to bear technology from the physical and engineering sciences. There has been a significant amount of debate concerning the type of training that such individuals should receive. In fact, there has even been debate as to what kind of people these disciplines represent.

For example, in 1968, Tichauer and Glaser[11] conducted a survey of the needs of engineering schools in the field of biomechanical and human factors education. One hundred sixty-seven engineering schools were canvassed by two surveys. One of the questions asked was: "How do you define biomedical engineering?" The answers varied from genuine attempts to answer the question to such comments as "There are ten different ways to define it" or "I don't define it at all" or "I wouldnt's use the word." There is still something of an identity crisis concerning who or what the biomedical engineer is. The desire, however, to bring about the application of physical science and engineering techniques in the field of medicine is sufficiently strong that there appears to be continuing interest in the field of biomedical engineering.

4.3 People Transfer. Another method of transferring information across disciplinary or organizational boundaries is to transfer people possessing the information. This is a variation of the person who is trained in two disciplines. However, in this case, the individual is not necessarily trained in the second discipline into which he is thrust either bv choice or circumstances. Usually, he brings a background of one discipline to a new job. In this case, the individual must essentially master the new field on his own. Still, there are numerous examples of the transfer of technology by the process of transferring people. Danhof[12] published a study of technology transfer by people transfer in 1969. In this study, he requested information from 352 former National Aeronautics and Space Administration employees who had accepted employment in other organizations. Of those who responded, 47% indicated that they had transferred NASA-generated technology to their new employers, and 95% indicated that they expected at some future time to transfer technical knowledge derived from their experience to their new employers.

In this study, the respondents were divided into two groups: those whose new employment was essentially the same as their NASA employment and those in which employment was substantially different. Only 33% of those having essentially the same employment reported transferring NASA technology. On the other hand, 67% of those with substantially different employment reported transfers. Thus, the frequency of technology transfer was notably higher when the new position was substantially different from the old position at NASA. From these studies, Danhof concluded (1) that when people are transferred under proper circumstances, the probability of technology transfer is high and, (2) that changes in employment and work circumstances are associated with high rates of technology transfer.

4.4. Computerized Information Searches. Although it is recognized that the transfer of documents such as journal articles, etc. between fields is not a very effective manner of transferring technology (it has already been listed as a barrier), it must be recognized that this is frequently the first step leading to the identification of technology which has the potential for transfer. As a result, improved techniques for searching the literature of various fields has some significance as an aid in overcoming interdisciplinary barriers. The development within the past 10 to 15 years of computerized information banks has made it significantly easier for the individual to locate documents pertinent to a given area. These computerized information sources are generally organized on keyword bases so that, by selecting a proper set of key words or descriptors, only those documents indexed under the particular set of descriptors will be selected by the computer from the entire document file.

4.5. Experimental Technology Transfer Programs. The idea of transferring technology between disciplines is essentially the concept of applying technology and information developed by one individual or group for a specific purpose to another individual or group for a secondary purpose. It has been apparent to those who have studied the processes of technology transfer that if technology transfer is allowed to proceed at its own pace, then transfer between disciplines occurs very slowly and in a random manner. Between 1958 and 1968, approximately 100 billion dollars were spent on research and development. Of that amount, approximately two-thirds was government funds. Because of this fact, the government has a strong interest in finding multiple uses for technology developed within its various supported programs. Indeed, if one is to obtain full value for the research and development dollar, then these secondary applications of technology must be accomplished. As a consequence, there have been a number of studies and experimental programs funded by the government to explore the methodology of technology transfer and to seek to find means of enhancing the probability that new technology will find its way into second uses.

It can be quickly recognized that one of the most significant problems is the fact that these barriers exist and there are few channels available for the flow of information, ideas, and technology between the disciplines. In an attempt to create effective avenues for the flow of technology and information between disciplines, several methodologies have been explored. One example is an experimental program undertaken by the National Aeronautics and Space Administration to attempt to find ways of transferring technology from the aerospace field into the biomedical field. This experimental program, called the Biomedical Application Team Program, has been in existence for approximately five years. It was immediately apparent that the ordinary method of transferring technology employed in the past was essentially passive. For example, articles were published in journals, and anyone interested could read the journal. If not, they remained unaware of the technology. Essentially, information is available in printed form, and if one wishes to use this information he must seek it and locate it in order to use it. The difference between the Application Team Program and conventional methodology is that the Application Team method actively seeks to establish channels for the flow of information and technology. Essentially, an agent (the Team) is introduced between the disciplines in order to act as a channel for the flow of ideas.

The Application Teams consist of interdisciplinary teams of physical scientists that attempt to interface between individual researchers in medicine and technology originators in the aerospace field. In this program, the Team members seek out specific biomedical problems which are impeding the work of biomedical researchers and then actively seek solutions to these problems. The problems identified by the Team are defined in precise language by the medical researcher and the Team member.

Following problem definition, solutions to the problem are sought within the aerospace complex. Searching for solutions is accomplished using several approaches. First, a computerized information searching service is employed to perform computer searches of the NASA document bank in the specific area of the problem. Although information obtained from the NASA document file has not been the primary means whereby technology has been transferred, searching of the NASA document files has nevertheless performed one very important function in a number of cases. It has frequently permitted the Team to identify engineering and physical scientists within NASA who are working in areas related to the solution of the problem. This identification procedure has then made it possible to contact the NASA researchers directly and bring to bear the expertise of these researchers in personal interaction with the medical researcher.

Another approach used in searching for solutions is to request suggestions from NASA personnel by circulating to the nine NASA research centers concise written statements of the individual problems. Circulation is accomplished at each research center by a Technology Utilization Officer who has a detailed knowledge of the research activities at his research center. Suggestions received are relayed to the medical researcher for evaluation. If suggestions appear pertinent to the solution of the problem, then efforts are made by the Team to produce effective interaction between the medical researcher and the NASA researcher to solve the problem. It has been found that personal interaction between knowledgeable medical researcher and knowledgeable physical scientist possessing information pertinent to the solution of the researcher's problem has been the most effective manner of producing technology transfer. The program thus provides information to medical researchers from fields that they would not normally contact. Once solutions to the problem have been obtained that are acceptable to the medical researcher, the Team acts as a catalyst to aid in implementation of these ideas. The primary responsibility for implementation of the technology lies with the medical researcher; however, the Applications Team assists in engineering consultation and in recommendations for ways of applying the technology.

Examination of this program shows that some of the elements of a biomedical systems engineering team are present including: (1) the inputs consisting of the definition of the problem and problem requirements given by the medical researcher, (2) the expertise of the interdisciplinary team within the various disciplines of engineering, (3) the use of the computerized information processing system to identify sources of technology, and (4) perhaps the most significant aspect of the program, the person-to-person contact.

4.7. Comments. The effects of specialization, language barriers, size of the information reservoir, and difficulty of transfer by the written word can all be reduced by the techniques just discussed. The other barriers discussed (organizational, alienation of scientists and administrators, resistance to novel solutions, and the "not-invented-here" syndrome) tend to be individual problems peculiar to certain organizations and types of people. Advice on people problems is beyond the scope of this paper.

However, one comment on organizational barriers may be appropriate. When organizational structure is a barrier, perhaps the most important action that can be taken is to recognize it. If there are no people problems or political problems present, then recognition that the barrier exists and appreciation of its undesirability are usually sufficient catalyst to bring into being forces within the administration desiring to eliminate the problem. In some cases, recognition may occur but the problem may be judged of secondary importance, i.e., subordinate to other primary (and conflicting) requirements imposed on the organization, so that no benefit is realized from recognition of the problem. It does appear, however, that in many cases organizational barriers are allowed to continue to exist primarily because we are not aware of their presence. I might add that these comments on the organization are perhaps more applicable to industrial organizations than to organizational structures within the medical field.

5. INTERDISCIPLINARY RESOURCES AVAILABLE TO THE INDIVIDUAL RESEARCHER

It would be unfair to enumerate the barriers without suggesting some ways in which they may be circumvented. Certainly, because of the cost of a systems engineering team, individual therapists cannot usually employ the full-blown, classic systems approach. On the other hand, there are resources available to the average therapist which may supply a broader input of interdisciplinary data to the solution of the problem than is likely to be present within the experience of the individual therapist. From a practical standpoint, then, it would perhaps be wise to look at some of these resources which are available. The use of these resources will not transform an individual's efforts into systems engineering; yet, the broadening of one's information base cannot be other than beneficial in the solution of problems. What are these resources? There are at least three classes of resources:

(1) Documentary.

(2) Commercially available technology.

(3) Research and development assistance (location and identification of technology).

Under the documentary resources, the most obvious is journal articles. The limitations of journal articles and written material in general have already been discussed; however, journals are definitely not passé. They still represent an important information resource, and for most areas, they represent a locally available resource--particularly, provided a university library is nearby. Admittedly, this resource is difficult and time-consuming to use, but if one has the time available, it can be a very useful source of information.

There are a number of federally supported information analysis centers located in various sections of the country that have as their primary function the collection of information in specific subject areas. These information centers generally provide thorough coverage of particular topic areas and can prove extremely useful. The Committee on Scientific and Technical Information of the Federal Council for Science and Technology has compiled a "Directory of Federally Supported Information Analysis Centers." This directory lists the services available and the scope of information residing within each center. This document is available from the National Technical Information Service of the U. S. Department of Commerce.

Another useful information resource is the "Directory of Information Resources in the United States" published by the National Referral Center for Science and Technology and available from the Superintendent of Documents of the U. S. Government Printing Office in Washington, D. C. This directory is devoted primarily to information resources in the physical sciences, biological sciences, and engineering.

Another very useful collection of information resources may be found in the "Encyclopedia of Information Systems and Services" published by Edwards Brothers, Ann Arbor, Michigan.

For international information systems, the "Inventory of Major Information Systems and Services in Science and Technology" is published by the Organization for Economic Cooperation and Development, Paris, France. This publication is available from the National Technical Information Service of the U. S. Department of Commerce. In seeking out these specialized information resources, your best ally is a good reference librarian.

While not attempting to catalogue all of the available computerized information resources, there are several which may be useful. First, there is one which I am sure that most people in the health care field are familiar with; namely, the MEDLARS information service. This service is provided by the National Library of Medicine of the Department of Health, Education, and Welfare, Public Health Service, in Bethesda, Maryland. The key words are primarily medical terms, and information residing in the information bank consists, in large measure, of excerpts from medical journals and related medical literature. Searches of the MEDLARS system can usually be obtained from libraries associated with medical universities. In addition, individual inquiries made directly by mail are also accepted by MEDLARS.

Second, the Engineering Index and the Chemical Abstracts are widely used resources in the fields of engineering and material science. These resources are published as abstracts on a periodic basis and are usually available in most large libraries. In addition to the abstracts, however, both of these services have also placed their abstract information on tapes so that computer processing can be used to abstract documents according to key word indices. Unfortunately, neither of these resources themselves provide a searching service. Instead, they provide magnetic tapes to user institutions. Many large firms have the tapes available and use them for information searching purposes. In addition, these tapes are available from some university computing centers.

Third, the NASA Regional Dissemination Centers provide computer searching of a variety of materials. The primary data base for the Regional Dissemination Centers is the NASA Aerospace Literature File. In addition, many of these centers include the Engineering Index tapes, the Chemical Abstracts tapes, the unclassified Department of Defense file, plus a variety of other smaller files on specialized subjects. There are six of these NASA Regional Dissemination Centers distributed across the United States so that in all likelihood, there is one at least in your general area.

In the area of commercially available technology there are a number of publications which can be of value in determining whether or not required technology is commercially available. The American Association for the Advancement of Science publishes a "Guide to Scientific Instruments" each year which can be an aid in locating manufacturers of general sciencific equipment. The "Thomas Register," available in most libraries, is a very general file which lists manufactured items by category so that one can determine the available suppliers of specific categories of equipment. A similar publication, yet specific to the electrical engineering field, is the "Electronic Engineers Master." This volume, also published yearly, lists the various categories of electronic equipment and instrumentation along with the manufacturers of the listed equipment. It, too, is available at many libraries.

The American Institute of Biological Sciences, Bioinstrumentation Advisory Council in Washington, D. C., publishes a number of information modules detailing equipment sources for specialized areas and provides advice on equipment selection. In the specific field of medical instruments, the Medical Electronics News, a periodical, publishes a yearly "Dictionary and Buyer's Guide Issue" which is a useful index of medical equipment suppliers.

Another source of information on currently available equipment which is so common that one scarcely needs to mention it is the manufacturers' representatives and salesmen. It must be admitted that manufacturers' representatives on occasion are a source of annoyance, taking up time which one might rather spend elsewhere, and also, that they cannot be depended upon to supply completely unbiased evaluations of the equipment which they happen to be representing. Nevertheless, they do indeed form a part of the information network. In this connection, we have discovered that the smaller companies are frequently quite helpful, particularly, when a specialized fabrication source is required (i.e., when a device is not currently available but is within the current state of the engineering art). Such small companies are located in almost every metropolitan area. They are frequently more responsive to individual needs and are quite often eager to help.

One of the problems to be faced in getting a specialized device fabricated is the problem of ensuring that the equipment, once it has been built, satisfies the particular application. When one contracts with an engineering organization to build a particular device to accomplish a particular purpose and when the resulting equipment does not accomplish that purpose, the fault can usually be traced to poor communications. The engineer does not understand the medical problem, and perhaps the medical researcher does not understand the engineering problem. We have found that it is very important not only to tell engineers the requirements or specifications of the equipment, but also to make sure that the engineer understands how the equipment is to be used and what other equipment is involved. There are often implicit assumptions made both by the engineer and by the medical personnel, which neither is aware that the other is making. A thorough discussion of the use to which the technology is to be put can frequently reveal these implicit assumptions with a considerable savings of time and cost.

The final category I have called "research and development assistance" or location and identification of new information and technology. There is one resource in this particular category which we (because it is so obvious) frequently neglect. I am speaking, of course, of one's own organization. If information or technology exists within the organization, the likelihood of obtaining direct and immediate assistance with problems is generally much higher within one's organization than from any other resource. If one requires new technology or information from outside his own field, the time required to become familiar with the activities going on within one's own organization is usually time most profitably spent. Obviously, this comment is more appropriate to larger organizations than to smaller ones.

There is a growing awareness especially among young people that technology <u>should</u> be contributing to social needs. Many schools of engineering are very receptive to cooperative projects and programs to develop specialized instrumentation or to apply new technology to the medical field. In most universities graduate students are frequently looking for thesis and dissertation topics which have some impact in the social area. In many of the engineering schools, professors have found that practical class projects in which an actual problem is solved by the class are significantly more valuable than routine laboratory exercises. This can be an extremely effective method for interaction between medicine and engineering. It also happens to be an area in which the medical researcher, limited by funds, can frequently participate since engineering schools are sometimes willing to furnish these services without charge.

Finally, I do not feel that I can close without mentioning again the resource represented by the experimental NASA Biomedical Application Team Program discussed earlier. Each Biomedical Application Team (there are presently three teams) is a multidisciplinary team of physical scientists and engineers.

The teams actively seek to promote the transfer of information and technology by direct person-to-person contact with individual medical researchers. The teams seek to identify problems which fit certain criteria (these criteria are imposed to eliminate problems with low transfer probability). The criteria are: (1) The problems must have no solutions available on the commercial market. (2) They must be discrete and must be defined in specific terms. (3) They must impede the progress of priority efforts of the researcher, and (4) they must, of course, appear amenable to solution by aerospace-related technology. I would like to quickly point out that this last requirement is not so restrictive as it may seem on the surface. Because of the extremely broad scope of disciplinary coverage provided in the NASA aerospace program and the resulting development of expertise in such a wide variety of disciplines, there are few problems which can quickly be rejected by this criterion. While the overall mode of operation of the teams is to work with certain specified medical schools and centers, the teams do respond to individual requests which are received. Consequently, this resource is available to the individual, within the constraints of the problem selection criteria.

6. CONCLUSIONS

In conclusion, although some have, in criticism, implied that the systems approach on small problems is only good common sense, I have tried to make the point that it is a very special kind of common sense. It is an informed common sense. Systems analysis is at its best when all of the available information pertinent to the particular problem can be marshalled, evaluated, and the optimum solution selected by objective processes. When one must make decisions without benefit of full information then he is practicing, at the minimum, a restricted kind of systems analysis. Emphasis, in this paper, has been placed on modified or imperfect systems analysis, i.e. when not all of the available information can be obtained. Surely one must conclude that even though all the available information pertinent to the solution of a problem cannot be obtained within the constraints imposed by an individual's particular situation, the use of those information resources which are available will result in better solutions than if the information is not utilized. Essentially, even though one may not be able to practice the full-blown classical systems approach, this fact should not be a deterrant to use of all of the resources which can be brought to bear on a specific problem. Stated in its simplest form, common sense, reinforced by valid information, is far superior to common sense alone.

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