Systems for Technological Information Transfer

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Since Sputnik I, the federal government and private organizations in the United States have spent several billion dollars to develop and operate better technological information systems. Users are still dissatisfied with the effectiveness and responsiveness of existing systems, especially those in newer areas of technological concern, such as the environment and energy. In this article, I examine some characteristics of the U.S. technological information "systems" as they have changed since 1930, contrast them with health care and personal transportation delivery systems, and urge a greater federal effort to strengthen national information resources.

"Technological information transfer" is the dissemination of what Fritz Machlup called "practical knowledge"—knowledge useful in one's work, decisions, and actions (*1*). "Technology" is equated with "how to do" and all that that implies in supporting theory, evaluation of alternatives, equipment processes, materials and facilities, and supporting procedures and technique.

Coupling Problem and Solution

The basic process in technological information transfer is the coupling of a problem and a solution. Most one-time problems in a small operation are solved with only limited information-gathering and analysis of alternatives. A shop foreman or police sergeant bases his decision primarily on personal experience. Getting fast access to all the information that would permit a careful study of alternatives is all but impossible for such problems, and the cost would be too high. However, in large operations, where the best solution has great value and more time is available, sophisticated analytic and evaluative staffs operate with the support of a large, complicated, and costly information file.

Coupling a problem and a solution must take place within human minds. It is a creative act. Its creative aspects range from the fairly trivial through the ingenious to the brilliant. Its importance to society was recognized by the framers of the U.S. Constitution in establishing the patent system. Yankee ingenuity has been a world-recognized fact for more than 200 years.

However, this information base for technological creativity in the civil industrial sector has been given low priority by top governmental policymakers. Private professional societies and trade associations have borne the burden of establishing and maintaining the nation's systems for transferring technological information in the manufacturing and service sectors. Agency administrators in medicine, defense, and agriculture, and, more recently, in nuclear energy and space technology, have created self-contained information transfer systems. Broad national policy has focused on systems that are especially beneficial to intellectual knowledge, such as the school, university, and public library systems. Consequently, separate information systems have been established for technology and the humanities, as well as for different branches of technology.

Structure of the U.S. Technological Information System

The mechanisms for transferring technological information have not changed appreciably in the past 30 to 40 years. They are not actually a system; rather, they are a mix of publicly supported and privately owned organizations, each pursuing its own discipline or problem-oriented objectives. Research results and some engineering and technological results are published in professional and trade journals. These reports are abstracted and indexed, and abstracts journals, newsletters, and indexes are published. Monographs and handbooks are prepared by experts in specialized subject areas and put out by private, university, and government publishers. Professional and trade association meetings provide for both formal and informal transfer of information. A great deal of person-to-person transfer of information occurs by telephone and direct contact. Special libraries (most of them industry-based) play a key role in providing local access to the system.

The most important changes in the system (all of which have taken place within the past 15 to 20 years) have been the following:

1) The advent of the technical report as a major records form, supplementing books and journals.

2) Federal subsidy, by means of page charges, of journal publication.

3) Development of the computer, electronic display devices, and microforms.

4) The creation, mostly by federal agencies or with federal subsidy, of computer-based files of abstracts and indexes for specific subjects, with subsequent distribution to specific user groups.

Although these changes have greatly improved the potential (and, in some cases, the actual) performance of the technological information system, they have also vastly complicated its structure and mode of use.

The User

One might hope that users would increase their efficiency in order to compensate for the added complexity of the system. But the physiological qualities of the human visual and auditory senses and of assimilation have not changed. For example, the telephone numbering code is based on the fact that most people can easily remember seven digits, or 23 bits of information. Although the rate of information assimilation can be increased by grouping or organizing information into chunks and by recoding it "in

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Table 1. System parameters involving the user.

Parameter	Transportation	Health care	Technological information
Definition of problem	Specific ("I want to go to X tomorrow"); easily articulated in system language	Specific ("I don't feel good," or "I hurt my arm"); seldom articulated in system language	Frequently poorly conceived; articulated with difficulty because of different systems and system languages
Expertise in use of system	None required for mass transport; automobile skills taught in school and at home	None required, other than knowing to call a doctor or to go to clinic; learned in childhood	Much expertise required; few opportunities available for training
Access to system	Few, well-known easy entries (travel agent, service station, and plane, bus, train terminals); accessible day and night	Well-known entries; not always easily accessible; units not always effectively linked to full system	Uncertain entry; each system unit competent within narrow limits and not well linked to remainder; accessible working days only
Alternatives and system response	Many alternatives; each satisfies user's basic need	Many alternatives; wide variation in effectiveness and user satisfaction	Many alternatives; wide variations in effectiveness, timeliness, and user satisfaction
Charges and system response	Higher prices give greater user convenience, comfort, and satisfaction	Little correlation between price and user satisfaction	Many system units give "free" or subsidized, standard quality service; moderate correlation between price and user satisfaction in other units

one's own words," the average person's assimilation of technical information appears to be no more than 150 to 200 words per minute (*2*).

The maximum amount of time a scientist or engineer devotes to interacting with the information system in science and technology has not changed in the last 25 years. Studies since 1948 have shown that scientists and engineers spend about 3 to 4 hours a day at most, on reading journals, talking with peers seeking information, and similar activitives (*3*). They allocate as much time to interaction with the information system as they feel is profitable and productive, and this amount of time has not changed for a number of decades. New users (for example, state and local governments and citizens' groups) want to spend much less time getting answers to their questions, and neither old nor new users are especially trained in the use of the total technological information system.

Effectiveness of the System

A primary measure of the effectiveness of the technological information system is its capacity to allow people with problems to get in touch with people (or records) with potential solutions. As the number (n) of people using the system increases, the number of potential couplings increases by approximately n^2. The number of scientists and engineers in the United States has grown tenfold, from 250,000 in 1930 to 2.5 million in 1970 (*4*). To maintain the same access to information for users in 1970 that users in 1930 had, the information system's switching and channel capacity would have to increase 100-fold.

In all likelihood, the potential switching capacity of the system has increased by that amount, but the "busy signals" encountered and the lack of adequate directories for making couplings have tended to nullify the increases. For example, the number of telephone handsets in the United States increased sixfold from 1930 to 1970 (*5*), but the time available to any one individual for interaction with others did not increase. Telephone calls have averaged four per instrument per day since 1930 (*6*). The few new switching mechanisms for information transfer, such as the National Referral Center and the Science Information Exchange created in the 1960's, have failed to aid a large fraction of those seeking technological information. Practicing technologists prefer to use their peers and fellow employees as directories to the information system because of ease, familiarity, and effectiveness. But the time available still limits actual use of the system.

The volume of technological information, as represented by the world's scientific and technical literature, increased roughly 16 times between 1930 and 1970, a doubling in annual output every decade roughly equivalent to the increased number of system users (*7*). The channel capacity required to reach each scientist and engineer would therefore have to be 16 times greater at the point of contact with the user, and much more in the trunk channels, in order to provide the same potential access per unit of time in 1970 as in 1930.

It is obvious that today's user cannot handle 16 times the volume of information that someone a generation ago could; their sensing, assimilation, and time limitations are equal. For the usefulness of the system to be constant, therefore, information condensers, transformers, and filters are required in proportion to the volume of information, number of users, and manner of system use. One could, of course, wish for an even more useful system, and I do.

The two basic modes of system operation are personal contacts and user interaction with recorded information. Personal contacts have proliferated as the recorded information system has proved less able to satisfy the needs of users. The telephone network is an important mechanism for personal contact, as are airplanes and automobiles. During the period 1930 to 1970, in addition to the increase in number of telephone handsets and the 200-fold increase in long-distance calls, automobile registrations increased 4-fold, highway lane miles 6-fold, airplane passenger miles 1000-fold, professional conferences and meetings 100-fold, and the bit capacity of major telecommunications circuits 100-fold (*5*).

Based on a combination of these facts and my own experience, I conclude that no limitations to the transfer of technological information are imposed by the physical unavailability of telecommunication facilities, automobiles, or airplanes—or by the unavailability of printing presses, paper, or microfilm. However, transferring information by means of the U.S. mail frequently imposes delays of several weeks. Statistics on libraries are difficult to obtain, but, as far as I can determine, there has been only a nominal growth (perhaps twofold) in the number of technical libraries in the past 40 years.

Signal-to-noise ratios are also a limiting factor. A good, and much-used, technique for increasing channel capacity is to increase the signal-to-noise ratio, along the lines suggested by Claude Shannon's information theory (*8*). Speech compression is a technique familiar to telephone engineers. Monographs and handbooks are literary examples of information compression. More recently, the rise of specialized information analysis centers has significantly increased the signal-to-noise ratio in many subject areas. Whether these techniques have enlarged the overall capacity of the system in the past 30 to 40 years and whether the overall signal-to-noise ratio has increased in the transfer of technological information are debatable. In the opinion of many experienced observers, the signal-to-noise ratio is actually decreasing (*9*). Formal presentations at professional meetings are acknowledged to be low in signal content—so much so that the usual rationale for attending such meetings is to meet and talk informally with peers.

Taking the ratio of monographs and handbooks to journal articles published annually as an index of signal compression, the evidence tends to support the theory of a decreasing ratio. The number of monographs and handbooks in science and technology in 1970 was 4 to 5 times the number in 1930, while journal literature was 16 times greater. Although it might be argued that one monograph today covers more journal articles that it did formerly, the evidence supports Curtis Benjamin's thesis that monographs are increasingly specialized and cover roughly the same volume of material (*10*).

Other important system parameters must be considered. How large a fraction of the user population must be served simultaneously? How fast must the system respond? How variable might be the quality of the response?

Qualitatively, it appears that, with respect to all three parameters, the systems transferring scientific and technical information today are being asked to do far more than they were in the 1930's and 1940's. A larger fraction of the users interacts with more of the information system, from the beginnings of research all the way to practical application. Examples are the continuing education of practitioners about new research findings, the increased number of science editors for newspapers and news magazines, the increased theoretical content of engineering curricula, and the shorter time between invention and application.

As in most other areas of life, so in information transfer, a fast response, a quick fix, is desired. Even computer time-sharing systems must get an answer to the user within 10 seconds in order to satisfy him. A day's delay in local mail delivery seems too much. Competition is a partial cause of the demand for speed, as is a general cultural change that emphasizes the value of time. Finally, the much greater variety of media and devices within the information system today leads to greater variety in the system's responses.

It becomes clear from this brief description of changes between 1930 and 1970 why, in spite of hundreds of millions of dollars spent, the system for transferring technological information to the user still leaves much to be desired. It also becomes clear that new patterns and structures for transfer will continue to evolve to take advantage of the effectiveness of new modes of communication. Conversely, old patterns and structures that are not effective will continue to atrophy. National policies, especially those that subsidize the operation and use of the various segments of the information system, will, however, affect the rate of change.

Technological Information and Other Practical Human Needs

Some further insights may be gained from analogies with systems serving other practical human needs—health and transportation. Several of the more important system parameters involving the user are compared in Table 1 and discussed below.

Definition of the problem. People can always express their transportation requirements precisely. In addition, they always know when they feel sick or hurt, although they cannot always treat or diagnose themselves. They are accustomed to question-and-answer dialogue with transportation and health care professionals in order to define precisely their problem and need.

People seeking technological information are usually imprecise in stating their needs, but frequently question the need for a professional intermediary to help define the problem in system language. It is rare that a mature adult will admit that he is not the master of his information system—which may be due to early childhood strivings toward, and later pride in, being able to read and write. There is usually no counterpart of this ego involvement in health care or transportation.

Expertise in the use of the system. Little user expertise is needed to take advantage of the health care system. Children learn about doctors and hospitals at an early age. Nor is the user expected to provide anything but the most elemental health care for himself. Professionals supply the bulk of health care services.

Very little expertise is required to use the transportation system, and that little is acquired by most people during their teens. Many schools provide driver education and training. Professionals operate the mass transportation systems—the buses, trains, airplanes, and subways.

Because of the variety of media and the separate systems in which it is stored and handled, the technological information system demands a fairly well-developed expertise in using or operating the total network; otherwise, the user must be satisfied with partial solutions. Some expertise in one or two information systems is usually developed during professional training, but as soon as the user needs information that is handled in a different system, he requires outside assistance. There are almost no opportunities for adults to develop skills for using the technological information system. There has even been regression in the availability of such opportunities during professional training.

Access to the system. The user knows to get in touch with a doctor or the police for health care, and he can do it at any time, day or night, although specific professionals are not always available.

In the case of transportation, there are a few, well-known access points—bus terminals, travel agents, service stations, airline ticket offices, and, today, the Amtrak terminal for train service on the most heavily traveled routes. Furthermore, these access points are open day and night.

But people seeking technological information have no such easy access. Small businesses and individuals most often rely on their suppliers or a local office of a government agency. Researchers turn to their special library or to the government agency whose mission is oriented toward their field of interest. Librarians and other information professionals are frequently unsure of which access route into the total system will yield the most useful results, because of their limited familiarity with the various system units. Engineers often turn to an obsolete handbook or to their fellow employees. In no case does the user get the same assured entry into the total information system as he does into the total transportation system. Furthermore, access to the technological information system is usually available only during business hours.

Alternatives and system response. There are, in most areas, a number of physicians and hospitals providing health care, the quality of which is variable, but usually acceptable. A specific physician or hospital accommodation is not always available, but the user has a directory (the *Yellow Pages*) of all physicians, from which he can select an untried alternative. Health care equipment is of variable quality, but it is used only by professionals.

Transportation alternatives also exist in heavily traveled sections of the United States: airlines, bus companies, railroads, and automobiles all compete with each other. Each mode of travel will completely satisfy the user's basic need, although with varying cost, speed, and comfort. There is almost no variation in the quality of system response caused by variation in professional staff. There is one combined schedule and directory for all airplanes, for all buses, and for all trains, and there are free road maps at every service station. Any manufacturer's automobile, airplane, or bus, furthermore, will operate on any oil company's gasoline and oil. The same highway suffices for cars and buses, and the same airport for most airplanes.

The seeker for technological information has more difficulty. This is partially because of the user's hope that his search will yield the one solution to his need that involves the least cost, least effort, and greatest effectiveness. "Technology" now has that image. More important, the difficulty is caused by the lack of systems and products compatibility in the information network. We have "progressed" from the time when differently sized books and differently cataloged books caused storage problems (and they still do), to the massive, computer-based information systems, each with a different vocabulary, indexing rules, access techniques, and output. The user's difficulty is increased by the fact that there are hundreds of directories, all of them incomplete and expressed in language and symbols chosen by the producer. As a result, there is no guaranteed satisfaction of the user's need.

Charges and system response. There are wide variations in the price of health care from one area of the United States to another, and even within a single urban area. But, with only a few exceptions, such as newly developed surgical technology, higher prices do not result in better quality health care as perceived by the user. The recent doubling of health care prices has not, for example, yielded healthier or more satisfied users. In transportation there are also wide variations in price, yet higher prices usually result in greater convenience and comfort, faster transportation, and greater user satisfaction.

The user needing technological information is confronted with a complex pricing arrangement that has little or no correlation with satisfying his needs. Many services, such as those offered by libraries, suppliers, and friends, are free of direct charges but are not usually geared to different user needs. Other services, such as those provided by several federal organizations, are partially subsidized but are unresponsive to individual needs. Still other services are offered by commercial enterprises; in these, higher prices usually result in better system response and greater user satisfaction. Most often, the user is unfamiliar with the full range of alternatives—unfortunately, so are information system professionals. Each tries to satisfy user requirements from a limited set of alternatives and frequently lacks a means of charging the user for higher quality service.

It may be concluded that a person can interact effectively and easily with the transportation system, less so with the health care system, and quite inadequately with the technological information system. To improve his interaction with the information system, the following steps appear desirable:

1) Specific training for all persons in high school, college, and adult school in the technological information system. Memorizing the Dewey decimal system is not the answer.

2) A broader, more intensive training of information professionals in the entire technological information system, in order that they may prescribe a better solution to a user's problem.

3) Much greater standardization of components of the information system. Styling changes should not cause system incompatibility.

4) Greater reliance on pricing for full cost recovery, in order to render higher quality service.

Federal Information Systems in Technology

Information systems in various branches of technology have been supported and operated by the federal government for many years. Notable examples are the National Library of Medicine, the Department of Agriculture, the U.S. Geological Survey, and the Weather Service. These systems (with the exception of the Weather Service) were created to provide bibliographic information about, and thereby access to, the literature in their special fields. The Weather Service provided synoptic data derived from its own observations. Until the 1960's, the systems were print-based, in the traditional library mode.

Beginning with the rapid increase in federal support for military and nuclear technology in the 1950's, several new federal information systems were established. The most notable are those of the Department of Defense, the Atomic Energy Commission, the National Aeronautics and Space Administration, and the Office of Education (*11*). The distinguishing features of these systems were their emphasis on the technical report; their use of new computer, telecommunications, and optical technologies; and their policy of free services for their specific clientele. The Department of Commerce's National Technical Information Service was also created to provide a central, public access to federally generated or supported technology, on a fee basis (*11*).

Does effective transfer of technological information require the establishment of federal information systems? In 1963, the President's Science Advisory Committee recommended (*9*) that mission-oriented federal agencies accept a "delegated agent" duty to ensure that effective technological information systems exist in their respective areas. Yet it also pointed out that the growth of federal systems should be guided in such a way as to avoid swamping systems in the private sector. Have the experiences of the past 10 years taught us differently, or have they reaffirmed these earlier conclusions?

The existing federal technological information systems (*12*) have a number of common elements that have contributed to their success in serving each system's group of users.

1) There are a few well-known means of access to each system.

2) The user is operating in a familiar field and formulates his problem in terms that are compatible with his system's ability to respond with solutions.

3) Each system produces its own directory and catalog of published material and people working in the field (*13*).

4) The systems include an array of information analysis centers specializing in compacting the raw information of interest to its users (*14*).

5) The systems include organized programs of symposiums, meetings, and training in the subject matter.

6) The systems are based on modern computer, optical, and telecommunications technologies.

7) Channel capacity and switching capacity in the systems are adequate.

8) Somewhat apart from the systems themselves, but contributing to their success in solving problems, is the availability of federal or state facilities and manpower to help find general solutions to identified problems.

To assemble, fund, and operate a technological information system embracing so many diverse functions and capabilities appears to be outside the sphere of private leadership. The lack of adequate information systems in aerospace, nuclear, military, medical, educational, and agricultural technology in the private sector was the raison d'être of the federal systems. Although the private information industry has made great strides in capability in the last 10 years, it seems out of the question to expect the industry to develop overall information systems for areas of technology in which federal agencies have missions.

There has been, however, a trend toward greater use of private information capabilities by federal agencies. Another trend has been toward user charges. The Department of Defense has led this movement and today relies mainly on the National Technical Information Service to provide information seekers with access to the unclassified Defense system—with full cost recovery from the user. A final trend has been the spin-off of information products and services from federal agencies to private operators.

The evidence of the last 10 years thus suggests that managers of federal technological information systems are taking steps that lead to greater involvement of the private sector in the operation of such information systems.

Conclusions

The technological area of greatest public concern today appears to be environmental pollution and conservation. At high policy levels, the new areas of concern also include energy and the faster application of more technology to U.S. manufacturing, construction, transportation, and service sectors, as well as to the operation of state and local governments, including crime prevention and law enforcement. In none of these areas is there a technological information system that has the traits of the existing federal systems. Instead, there are fragmentary operations of limited scope being carried out by numerous public and private organizations.

There are federal agencies with missions in several of these areas—environmental pollution and conservation, transportation, and the manufacturing and service industries. In the areas of energy, construction, and state and local government technology there are no federal agency missions as yet.

The urgent need for more effective transfer of technological information in these areas makes it equally urgent that the appropriate federal agencies be charged with developing information systems. This is one of the recommendations of the President's Science Advisory Committee (*9*). The experiences of federal agencies that have pioneered in similar systems development should be of great value. Especially noteworthy is the greater capability of the private sector to operate large parts of the systems. Concurrently with the development of more effective, mission-oriented technological information systems, increased federal effort appears necessary to encourage the integration and coordination of the separate systems into a more coherent, more accessible network. The effort should be mounted.

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