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Paper Twenty Three

Information Technology and Aerospace Knowledge Diffusion: Exploring the Intermediary-End User Interface in a Policy Framework

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Information Technology and Aerospace Knowledge Diffusion: Exploring the Intermediary-End User Interface in a Policy Framework

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Federal attempts to stimulate technological innovation have been unsuccessful because of the application of an inappropriate policy framework that lacks conceptual and empirical knowledge of the process of technological innovation and fails to acknowledge the relationship between knowledge production, transfer, and use as equally important components of the process of knowledge diffusion. This article argues that the potential contributions of high-speed computing and networking systems will be diminished unless empirically derived knowledge about the information-seeking behavior of the members of the social system is incorporated into a new policy framework. Findings from the NASA/DoD Aerospace Knowledge Diffusion Research Project are presented in support of this assertion.

INTRODUCTION

Since 1965, seven out of ten U.S. high technology industries have lost world market shares (Young, 1985). The President's Commission on Industrial Competitiveness (1985, p. 6) concluded that "the nation's ability to compete has declined over the past 20 years; that we must be able to compete [internationally] if we are going to meet our national goals of a rising standard of living; and that we, as a nation, can no longer afford to ignore the competitive consequences of our actions or our inactions." With the exception of the commercial sector of the U.S. aerospace industry, American productivity, which is at the heart of competitiveness, has been surpassed by the world's major industrialized nations (Porter, 1990).

Since the 1960s, the United States has made numerous, but largely unsuccessful, attempts to

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stimulate civilian technological innovation and to restore U.S. competitiveness. The lack of success is attributable largely to the application of an inappropriate policy framework. This framework lacks conceptual and empirical knowledge of the process of technological innovation and fails to acknowledge the relationship between knowledge production, transfer, and use as equally important components of the knowledge diffusion process. Recent federal initiatives in high-speed computing and networking systems, designed to improve the nation's computing, communication, and information infrastructure, represent the latest in a series of efforts to increase research productivity and to speed the process of technological innovation. The potential contributions of information technology (i.e., computing and communications technology) will be diminished, however, unless empirically derived knowledge regarding the information-seeking behavior of the members of the social system—those who are producing, transferring, and using technical information—is incorporated into a new policy framework. Research collected as part of a four-phase study of aerospace knowledge diffusion is presented in support of this assertion.

BACKGROUND

Traditionally, the federal government has limited itself to activities that are either directly or explicitly tied to an existing responsibility of a specific government agency. Since the early 1960s, however, government has taken an increasingly active role in stimulating technological change and innovation in the civilian economy. Economic vulnerability, lagging productivity, unfavorable trade balances, loss of traditional markets, and unemployment are the primary reasons for government intervention. Although federal programs have contributed substantially to stimulating technological innovation, by and large they have failed to stimulate civilian (as opposed to defense and space-related) research and development (R&D).

Failure of U.S. Technology Policy

Averch (1985) suggests that these programs represent political rather than technical failures. Mowery (1983) believes that the failure is both political and technical and attributes it to the application of an inappropriate theoretical economic framework, one that ignores or does not account for the effective transmission and utilization of complex research results and technological information. In particular, these programs overlook the abilities and limitations of organizations engaged in innovation to exploit extramural research, thus ignoring the relationship between knowledge production, transfer, and utilization as equally important components of the innovation process.

Unlike Japan, which has a managed and centralized approach to R&D, the United States funds R&D using various methods through numerous agencies of the executive branch. Federal R&D activities are undertaken by thousands of engineers and scientists in academia, government, and industry, and receive oversight, but not coordination, from many committees and subcommittees in both the executive and legislative branches of government (Pinelli, 1990). Existing federal technology policy continues to be driven by a supply-side model that is product, not process-oriented. It encourages innovation and emphasizes knowledge production but not its transfer and utilization.

Although considerable research into technological innovation and policy analysis has been conducted by various disciplines and from numerous perspectives, the policy implications of this research and investigation are inconsistent and contradictory, and are simply not used for policy development. In fact, Tornatzky and Fleischer (1990, p. 241) suggest that the "United States has no coherent innovation or technology policy. The United States does, however, have many programs and numerous policies which cut across political jurisdictions and the idiosyncratic missions and mandates of single agencies which are more or less responsive to a series of shifting political alliances and imperatives."

Implications for U.S. Technology Policy Development

There is general consensus that current conceptual and empirical knowledge regarding both the process of technological innovation and U.S. government intervention is lacking. According to Curlee and Goel (1989), recognition is growing that technology transfer and diffusion are the "key" to the success of technological innovation. Consequently, understanding the influences that motivate innovation and channel its direction is necessary if government intervention is to successfully increase the production of useful innovation. Nelson (1982, p. 8) and Pavitt and Walker (1976, p. 96), in their review and analysis of government policies and programs toward technological innovation, state that federal innovation policy and prescription encourage innovation, not its adoption. Knowledge transfer and utilization [diffusion] are "very inadequately served by market forces and the incentives of the market place." They conclude that government would better serve technology policy by assuming a more active role in the knowledge diffusion process and formulating policies and programs that encourage and improve communications between users and producers of knowledge.

The federal government has successfully stimulated innovation in aerospace, agriculture, and biomedical R&D, as well as broader generic R&D in the National Institute of Standards and Technology (NIST). An examination of these programs and their knowledge diffusion components suggests several points that should be considered in formulating federal technology policy. Although primarily technical, these points also have an obvious political component.

- Any attempt at intervention and stimulation of civilian R&D must take into account the unique characteristics of the various industries. The character of the industry which is the presumed beneficiary of the R&D program is central to its potential for success. The structure of the industry must lend itself to taking advantage of the programs' results; the leaders of the industry must be interested in and not opposed to the programs; and the government/industry relationship needs to be based on long-standing trust and the perception of mutual benefit.

- Careful attention must to be given to the balance between user (industry) needs and the institutional/technical capabilities of the R&D institutions in designing research programs. Research in and of itself is not sufficient to ensure that it will be put to use in commercial applications or used productively.

- There must be a coordinated system for coupling knowledge with people who would use it in the field. Information programs must collect, control, and diffuse the results of federally funded R&D. In addition, the system must include a component that collects, translates, evaluates, and diffuses the results of foreign R&D to U.S. academic, government, and industry users.

- The success of these programs is largely attributable to the adoption of an information processing model that takes into account the effective transfer and utilization of research resulting from federally funded R&D. Disseminating research results to industry is important, but knowledge about how a specific industry can effectively utilize federal research results must also be actively conveyed. As David (1986, p. 387) notes, "there is far more to public policies and actions affecting technology diffusion than the information dissemination programs." He suggests that the United States should develop a coherent, integrated set of policy goals directed at creating and utilizing technological capabilities. These policy goals must recognize that the entire process of technological innovation is fundamentally an information processing activity in which scientific and technical information (STI) is used to reduce economic and technological uncertainty (Rogers, 1982).

Federal Scientific and Technical Information Policy

Policymakers generally agree that STI derived from federally-funded R&D can be used to enhance technological innovation and economic competitiveness. Studies show a positive relationship between federally funded STI and successful innovation, technical performance, and increased productivity. But, as Solomon and Tornatzky (1986) point out, "While STI, its transfer and utilization, is crucial to innovation [and competitiveness], linkages between [the] various sectors of the technology infrastructure are weak and/or poorly defined" (p. 43). Defining and understanding these linkages is critical for formulating U.S. technology policy that would recognize the inherent relationship between technological innovation and STI resulting from federally funded R&D. However, it is obvious that the United States lacks a coherent or systematically designed approach to transferring the results of federally funded R&D to the user (Ballard, et al., 1986).

Policy instruments such as the Stevenson-Wydler Technology Innovation Act of 1980 (P.L. 96-480), the Federal Technology Transfer Act of 1986 (P.L. 99-502), the Japanese Technical Literature Act of 1986 (P.L. 99-382), Executive Order (E.O.) 12591, "Facilitating Access to Science and Technology" (April 10, 1987), and Office of Management and Budget (OMB) Circular A-130, "Management of Federal Information Resources," have shaped the legislative and regulatory environment for federal STI policy. Excluding A-130, the intent of these instruments is (1) to develop a predominant position for the United States in international markets by facilitating technology transfer from government laboratories and (2) to provide the inducements for federal engineers and scientists to nurture the transfer process. In addition, some of these instruments provide a mechanism for the collection and dissemination of foreign STI in the United States. The intent of A-130, which is concerned with the management of information as a resource, includes federal STI. According to OMB, STI conforms to a standard information life cycle and does not exhibit any unique characteristics calling for the development and implementation of a separate information policy framework. Attempts by OMB to regulate all information with a single policy instrument fail to recognize the linkages between federal technology policy and federally- funded STI; thus, from a policy standpoint, A-130 negates attempts by the Congress to promote innovation and competitiveness (Hernon & Pinelli, 1991).

A number of recently proposed policy instruments focus on the development of the nation's information technology infrastructure and the electronic dissemination of federal information. For example, the proposed Improvement of Infomation Access Act (H.R. 3459) deals with standards, pricing, and access to government information in electronic formats. The American Technology Preeminence Act of 1991 (H.R. 1989 and S. 1034) proposes a feasibility study for FEDLINE, a government information locator system to be operated by NTIS. The Wide Information Network for Data Online (WINDO) Act of 1991 (H.R. 2772) sets forth a Government Printing Office (GPO) program to provide public access to a wide range of government electronic databases. In addition, the GPO has unveiled a strategic plan that outlines initiatives for an information locator and provision system based on satellite transmission.*

The High Performance Computing Act of 1991 (P.L. 102-194) establishes both a federal R&D program in high-performance computing and communications (HPCC) and the National Research and Education Network (NREN). The NREN will support technological innovation by linking research and educational institutions with industry and government; it is intended to ensure the interoperability of federal and other networks and to provide users with access, as appropriate, to computing facilities, electronic information resources, and other research tools in all sectors. The Act authorizes expenditures of $2.9 billion for fiscal year (FY) 1992 to 1996, to be allocated to seven federal agencies. NASA's portion for fiscal years 1992 and 1993 is $160.3 million, which is authorized to deploy aeronautics and space application supercomputer testbeds ($14.1 million), to develop software tools and conduct computational research ($61.4 million), to provide high-speed network connections among NASA, industry, and academic researchers ($9.8 million), and to foster research into high-performance computing ($3.8 million) (Office of Science and Technology Policy, 1992). The Act emphasizes linking government, industry, and academia for distributed access to HPCC technologies and the transfer of HPCC technologies to the civilian sector; relatively little emphasis is placed on the role of HPCC technologies in the dissemination and utilization of STI to support technology transfer in general.

** See the perspective offered by Kelley, in this issue, for discussion of GPO's plans.*

The Transfer of Federally Funded STI

Three models or approaches have dominated the "transfer" of federally funded R&D (Ballard et al., 1989; Williams & Gibson, 1990). While variations of the models or approaches have been tried, federal STI transfer activities continue to be driven by a supply-side model. Scholars such as Branscomb (1991) argue, however, that this approach and the "trickle-down" benefits associated with the funding of basic research and mission-oriented R&D are inadequate for developing a U.S. technology policy.

- The **appropriability model** stresses the production of knowledge by the federal government that would not otherwise be produced by the private sector. It assumes that competitive market pressures will promote the use of that knowledge. This model emphasizes the supply (production) of basic research as the driving force behind technological development and economic growth and assumes that the results of federal R&D will be rapidly assimilated by the private sector. Deliberate transfer mechanisms and intervention by information intermediaries are viewed as unnecessary. According to this model, good technologies sell themselves and offer clear policy recommendations regarding federal priorities for improving technological development and economic growth. This model incorrectly assumes that the results of federally funded R&D will be acquired and used by the private sector, ignores the fact that most basic research is irrelevant to technological innovation, and dismisses the process of technological innovation within the firm. The most appropriate role for information technology in this model is to facilitate STI production.

- The **dissemination model** emphasizes the need to transfer information to potential users and embraces the belief that merely producing knowledge is not sufficient to ensure its fullest use. Linkage mechanisms, such as information intermediaries, are needed to identify useful knowledge and to transfer it to potential users. This model assumes that if these mechanisms are available to link potential users with knowledge producers, then better opportunities exist for users to determine what knowledge is available, acquire it, and apply it to their needs. The strength of this model rests with the recognition that STI transfer and use are critical elements of the process of technological innovation. Its weakness lies with the fact that it is passive, for it does not take users into consideration except when they enter the system and request assistance; however, user requirements are seldom known or considered in the design of information products and services. This model employs one-way, source-to-user transfer procedures that are seldom responsive in the user context. In this model, the role of information technology is expanded to emphasize information storage and retrieval, but retrieval is accomplished by intermediaries who are required to have more familiarity with the activities of the knowledge producers than the potential users.

- The **knowledge diffusion model** is grounded in theory and practice associated with the diffusion of innovation and planned change research and with clinical models of social research and mental health. Knowledge diffusion emphasizes "active" intervention as opposed to dissemination and access; stresses intervention and reliance on interpersonal communications as a means of identifying and removing interpersonal barriers between users and producers; and assumes that knowledge production, transfer, and use are equally important components of the R&D process. This approach also emphasizes the link between producers, transfer agents, and users and seeks to develop user-oriented mechanisms (e.g., products and services) specifically tailored to the needs and circumstances of the user. It makes the assumption that the results of federally funded R&D will be underutilized unless they are relevant to users and ongoing relationships are developed among users and producers.

The problem with the knowledge diffusion model is that (1) it requires a large federal role and presence and (2) it runs contrary to the dominant assumptions of the established federal R&D policy system. Although U.S. technology policy efforts rely on a "*dissemination-oriented*" approach to STI transfer, other industrialized nations, such as Germany and Japan, are adopting diffusion-oriented STI policies that increase users' power to absorb and employ new technologies productively. This model uses proactive information intermediaries and information technology to enhance both formal and informal communication among all participants in the innovation process. It encourages the user-oriented development and evaluation of STI products and services.

Limitations of the Existing Federal STI Transfer Mechanism

The existing federal STI transfer mechanism is composed of two parts—the **informal** which relies on collegial contacts, and the **formal** which relies on surrogates, information products, and information intermediaries to complete the producer to user transfer process. The producers are the federal R&D "mission" agencies and their contractors and grantees. Producers depend on surrogates and information intermediaries to operate the formal transfer component.

Knowledge producer surrogates serve as repositories or clearinghouses for the producers and include the Defense Technical Information Center (DTIC), the NASA Center for AeroSpace Information (CASI), and the National Technical Information Service (NTIS). Information intermediaries are, in large part, librarians and technical information specialists in academia, government, and industry. Those representing the producers serve as what McGowan and Loveless (1981) call "knowledge brokers" or "linking agents." According to Allen (1977), information intermediaries connected with users act as "technological entrepreneurs" or "gatekeepers." The more active the intermediary, the more effective the transfer process (Goldhor & Lund, 1983). Active intermediaries take information from one place and move it to another, often face-to-face. Passive information intermediaries, on the other hand, "simply array information for the taking, relying on the initiative of the user to request or search out the information that may be needed" (Eveland, 1987, p. 4).

The major problem with the total federal STI system is "that the present system for transferring the results of federally funded STI is passive, fragmented, and unfocused." Effective knowledge transfer is hindered by the fact the federal government "has no coherent or systematically designed approach to transferring the results of federally funded R&D to the user" (Ballard et al., 1986, pp. 2-3). Approaches to STI transfer vary considerably from agency to agency and, in any given agency, have changed significantly over time. These variations reflect differences between agencies (i.e., legislative mandates), the interpretation of their missions, and budgetary opportunities and constraints. In their study of issues and options in federal STI, Bikson and her colleagues

(Bikson, Quint, & Johnson, 1984) found that many interviewees considered dissemination activities "afterthoughts, undertaken without serious commitment by federal agencies whose primary concerns were with [knowledge] production and not with knowledge transfer." Therefore, "much of what has been learned about knowledge transfer has not been incorporated into federally supported STI transfer activities" (p. 22).

The specific problem with the informal part of the system is that knowledge users can learn from collegial contacts only what those contacts happen to know. Ample evidence supports the claim that no one researcher can know about or keep up with all the research in his or her area(s) of interest. Two problems exist with the formal part of the system. First, it employs one-way, source-to-user transmission even though one-way, supply-side transfer procedures do not seem to be responsive to the user context (Bikson et al., 1984). Rather, these efforts appear to start with an information system into which the users' requirements are retrofit (Adam, 1975). The consensus of the findings from the empirical research is that interactive, two-way communications are required for effective information transfer (Bikson et al., 1984).

Second, as just suggested, the formal part relies heavily on information intermediaries to complete the knowledge transfer process, but a strong methodological base for measuring or assessing the effectiveness of the information intermediary is lacking (Kitchen & Associates, 1989). The impact of information intermediaries is likely to be strongly conditional and limited to a specific institutional context. To date, empirical findings on the effectiveness of information intermediaries and the role(s) they play in knowledge transfer are sparse and inconclusive (Beyer & Trice, 1982).

The formal part of the transfer mechanism is particularly ineffective because STI is not organized and structured according to problem relevance. More to the point, putting STI to use frequently requires transferring it to a use context that is quite different from the context in which it was produced or originally packaged. This problem is complicated by the fact that STI is organized along traditional disciplinary lines as are subject matter indexes, abstracts, and key words. This organizational scheme makes multidisciplinary retrieval extremely difficult for users and (typically nontechnical) information intermediaries alike.

The information systems used to store and retrieve federal STI further limit its transfer. In fact, these systems are misnamed: they store and retrieve bibliographic citations rather than STI. The citations are so devoid of structure that they are usually arranged chronologically by year and/or authors' last names. Researchers typically need STI that is problem-oriented and organized according to products, processes, and procedures. They do not want citations, but rather a source that exhibits an understanding of the major topics and paradigms in their field. Although considerable progress has been made in information storage and retrieval research in the past fifteen years, most of these systems still employ Boolean logic as a search structure. Few of the advances such as vector processing retrieval strategy and expert systems designs have been incorporated into federal STI systems, most of which remain tied to a 1960s model of information storage and retrieval. Furthermore, the use of information technology to support informal communication among all players in the diffusion process has not been fully utilized.

KNOWLEDGE DIFFUSION IN THE U.S. AEROSPACE INDUSTRY

The U.S. aerospace industry accounts for more than 25 percent of all the nation's R&D expenditures, with a total investment of $24.3 billion in 1990 (Aerospace Industries Association of America, 1990). In 1990, aerospace ranked sixth in value of shipments and tenth in employment among all U.S. industries. More important, aerospace is the nation's leading exporter, sending products abroad worth $38 billion to 135 countries around the world in 1990. Aerospace produces the largest trade surplus of any U.S. industry ($26 billion in 1990), which significantly reduces the nation's merchandise trade deficit (U.S. Department of Commerce, 1992). In short, the U.S. aerospace industry is a national and global leader and a critical element of the U.S. economy.

The U.S. aerospace industry faces increasing challenges overseas. While the United States retains both market and technology leadership within the global aerospace industry, its position has eroded. In 1990, U.S. aerospace shipments still led the world but shrank to less than 60 percent of the worldwide market. This decline reflects the success of other countries in their efforts to foster the growth of their national aerospace industries. Many foreign governments have strong ambitions for competitive aerospace industries and have supported their growth with subsidies for product developr ent and production. They have also required of..ets and technology transfers in which purchases of U.S. aerospace products are contingent on their own firm supplying some of the components. In addition, some governments have encouraged consolidation and cooperation among local companies to reduce domestic competition and thus enable them to compete more effectively with established U.S. companies (U.S. Department of Commerce, 1992).

Aerospace Knowledge Diffusion Research

We have organized a research project to study aerospace knowledge diffusion. Sponsored by NASA and the Department of Defense (DoD), the NASA/DoD Aerospace Knowledge Diffusion Research Project is being conducted by researchers at the NASA Langley Research Center, the Indiana University Center for Survey Research, and Rensselaer Polytechnic Institute. This research is endorsed by several aerospace professional technical societies, including the American Institute for Aeronautics and Astronautics (AIAA), the Society of Automotive Engineers (SAE), and the Royal Aeronautical Society (RAeS). In addition, it has been sanctioned by the Technical Information Panel of the Advisory Group for Aerospace Research and Development (AGARD), and the AIAA Technical Information Committee.

This four-phase project is providing descriptive and analytical data regarding the diffusion of aerospace knowledge at the individual, organizational, national, and international levels. It is examining both the channels used to communicate and the social system of the aerospace knowledge diffusion process. Phase 1 investigates the information-seeking behavior of U.S. aerospace engineers and scientists and places particular emphasis on their use of federally funded aerospace R&D and U.S. government technical reports. Phase 2 examines the industry-government interface and places special emphasis on the role of information intermediaries in the aerospace knowledge diffusion process. Phase 3 concerns the academic-government interface and places specific emphasis on the information intermediary-faculty-student relationship. Phase 4 explores the information-seeking behavior of non-U.S. aerospace engineers and scientists in selected countries. The use of information technology in the knowledge diffusion process is addressed in all phases of the research.

As scholarly inquiry, our research has both immediate and long-term purposes. In the first instance, it provides a practical and pragmatic basis for understanding how the results of NASA/DoD research diffuse into the aerospace R&D process. Over the long term, it provides an empirical basis for understanding the aerospace knowledge diffusion process itself and its implications at the individual, organizational, national, and international levels. The results of the project should provide useful information to R&D managers, information managers, and others concerned with improving access to, the quality of, and the utilization of federally funded aerospace STI (Pinelli, Kennedy, & Barclay, 1991).

Related Research

To remain a world leader in aerospace, the United States must improve and maintain the professional competency of its engineers and scientists, increase the R&D knowledge base, improve productivity, and maximize the integration of recent technological developments into the R&D process. How well these objectives are met, and at what cost, depends on a variety of factors, but largely on the ability of U.S. aerospace engineers and scientists to acquire and process the results of federally funded R&D. In terms of empirically derived data, very little is known about the diffusion of knowledge in the aerospace industry both of the channels used to communicate and the information behavior of the members of the aerospace social system. The federal government's commitment to high-speed computing and networking systems presupposes that information technology will play a major role in the aerospace knowledge diffusion process. However, little is known about information technology needs, uses, and problems within the aerospace knowledge diffusion process.

Information Technology—Its Use in Engineering

Computer networks are playing an increasingly important role in engineering work because they link design and analysis tools with other important resources to create integrated engineering information systems (EIS) that engineers can use from their own desktops. Heiler and Rosenthal (1989, p. 431) define an EIS as the combination of "software tools, database managers, databases and hardware to provide integrated environments for engineering design and management." Mailloux (1989) reviews current literature on EIS. She provides an overview of a variety of engineering systems and devotes considerable attention to a discussion of how EIS support engineering work and communication. Integrated systems for computing and communications are particularly important because of the diverse nature of the work that EIS are meant to support: "20% of an engineer's time is spent in the intellectual activities of engineering—conceiving, sketching, calculating, and evaluating—with the remaining 80% spent on activities associated with creating, accessing, reviewing, manipulating, or transferring information" (Mailloux, 1989, p. 239).

Phases of the NASA/DoD Aerospace Knowledge Diffusion Research Project

Phase 1:
Investigates the information-seeking behavior of U.S. aerospace engineers and scientists and places particular emphasis on their use of federally funded aerospace R&D and U.S. government technical reports.

Phase 2:
Examines the industry-government interface and places special emphasis on the role of information intermediaries in the aerospace knowledge diffusion process.

Phase 3:
Concerns the academic-government interface and places specific emphasis on the information intermediary-faculty-student relationship.

Phase 4:
Explores the information-seeking behavior of non-U.S. aerospace engineers and scientists in selected countries.

Electronic data interchange (EDI) is used to exchange orders and invoices with vendors and suppliers, and contracts with clients and customers (Beckert, 1989; Purton, 1988). Thus, networks are also used in engineering environments to facilitate formal business communication outside the firm. Networks are used in some firms for information retrieval (IR) in connection with both in-house and commercial databases.

Information retrieval systems have received mixed reviews from engineers. Christiansen (1991, p. 21) discusses the results of an informal IEEE survey on how engineers obtain the information they need to do their jobs. He reports that engineers have difficulty performing online searches and often obtain inadequate results. He also interprets the tendency of engineers to "scan and save" large amounts of material as a response to their dislike of retrieval systems. Breton (1981 and 1991) presents a more compelling argument for the underutilization of information retrieval systems. He concludes that the informal and visual material that is important to engineers is not included in most IR systems. Furthermore, he claims that current indexing techniques fail to retrieve information according to those dimensions, such as "desired function," that are useful to engineers. Gould and Pearce (1991) describe the results of an assessment, based largely on interviews, intended to relate information needs in engineering to the current capabilities of systems for storing, organizing, and disseminating that information.

Finally, the literature suggests that engineers also use electronic networks for interpersonal communication. Borchardt (1990, p. 135) includes electronic mail among his suggestions for improving in-house technical communication in order to facilitate the sharing of ideas, provide a more stimulating work environment, and prevent the duplication of efforts. Beckert (1990, p. 68) notes that engineers can use electronic mail to send text, data, and graphics to their colleagues and to automate the notification of status changes among engineering, manufacturing, and external entities. She notes that electronic communication eliminates telephone tag and problems associated with time-zone differences, and also saves time in scheduling meetings and responding to technical questions. Mishkoff (1986) describes computer conferencing as the answer to the problems corporations face when they employ geographically dispersed work groups. He reports that Hewlett-Packard employs thousands of engineers in over seventy divisions, one-third of which are located outside the United States. He also describes how computer conferencing is used in place of more expensive mechanisms to allow groups of engineers to share knowledge efficiently and to coordinate their work (Mishkoff, 1986, p. 29).

Information Technology—Its Use in Aerospace

The aerospace industry possesses a number of characteristics that make it a natural environment for the use of information technology. It is a high technology industry, already highly computerized. It involves significant R&D, which is a communication intensive activity. Moreover, its end products are highly complex, calling for a great deal of work task coordination and the integration of information created by large teams of people. In describing the business and technology strategy in place at British Aerospace, Hall (1990) emphasizes the need for increased computing and communications capabilities in aerospace firms aiming to design, develop, make, and market complex systems while maintaining a technical competitive edge and reducing costs. He notes that a number of typical information technology benefits are particularly relevant to the aerospace industry, such as "improved productivity, better competitive edge, reduced time scales, closer collaboration, more streamlined management, better commonality of standards across sites, more operational flexibility, [and] constructive change of work force skill levels" (Hall, 1990, p. 16-2).

Hypothetically, if information were not readily available, less actual information use would occur and less value would be derived from information seeking, thereby increasing the fundamental cost of R&D.

Rachowitz et al. (1991) describe efforts at Grumman Aerospace to realize a fully distributed computing environment. Grumman's goal is to implement a system of networked workstations in order to "cost-effectively optimize the computing tools available to the engineers, while promoting the systematic implementation of concurrent engineering among project teams" (p. 38). The network includes PCs and software to be used for communication. Grumman assumes that their computer/information-integrated environment will result in "product optimization quality products manufactured with fewer errors in shorter time and at a lower cost" (p. 66).

Black (1990, p. 13–4) presents a brief overview of the uses and advantages of computer conferencing systems, noting that computer conferencing is a powerful tool for information transfer in all areas of R&D. Molholm (1990) describes the application of the Department of Defense Computer-aided Acquisition and Logistics Support (CALS) initiative to the aerospace community. CALS mandates the use of specific standards for the electronic creation and transmission of technical information associated with weapons systems development. Eventually all Department of Defense contractors and subcontractors will be required to create and distribute in digital form all the drawings, specifications, technical data, documents, and support information required over the entire life cycle of a military project. Thus, the CALS system may provide a significant impetus for electronic networking in aerospace firms.

The literature reveals that a number of engineering organizations, including those in aerospace, are using electronic networks for a variety of communication activities, distributed computing, and shared access to information resources. Networks are being implemented to serve organizational goals and business strategies, that is, to speed and improve product development and achieve cost savings. The literature also hints at a number of factors that may hinder network use, such as security and proprietary concerns, the failure of indexing techniques to retrieve stored information in a way useful to engineers, and the substantial financial outlays required to implement networked systems.

Studies of information technology needs, uses, problems, and impacts in engineering environments are scarce. Furthermore, the literature is fragmentary and anecdotal. Few empirical studies have been reported in the literature. Shuchman (1981) conducted a broad-based investigation of information transfer in engineering. The respondents represented fourteen industries in the following major engineering disciplines: aeronautical, chemical and environmental, civil, electrical, industrial, and mechanical. As part of this study, she examined "the attitudes [of engineers] toward and use patterns of computer and information technology in an effort to forecast the potential value of new information technologies" (p. 36). Overall the survey results indicated that computer and information technology has high potential usefulness but relatively low use among engineers. In reviewing this finding, it is important to keep in mind that the state of the art in computer and information technology has changed dramatically since Shuchman's study was released.

In Shuchman's study, respondents were asked to indicate the use, nonuse, and potential use of twenty-one information technologies categorized into four groups. Overall, aeronautical engineers made greater use of information technologies than did the other respondents. Aeronautical engineers also reported the highest use of "information transmission technologies" (fax, telex, teleconferencing, and video conferencing). Of the emerging technologies (e.g., digital imaging), they reported the highest rate of current use and predicted use.

A pilot study conducted as part of Phase 1 of the NASA/DoD Aerospace Knowledge Diffusion Research Project investigated the technical communications habits and practices of U.S. aerospace engineers and scientists (Pinelli et al., 1989). One objective of this study was to determine the use and importance of information technology to them. Approximately 91 percent of the respondents reported using information technology to communicate STI. Approximately 95 percent of those respondents who reported using this technology indicated that it had increased their ability to communicate. The lowest rates of use for any technology were those reported for the mature technologies (e.g., micrographics). The rate of use for maturing technologies (e.g., electronic databases) was relatively high, approximately 60 percent. Overall, 50 to 60 percent of the respondents predicted that they would use the nascent or emerging technologies (e.g., electronic networks).

The Information Intermediary and Aerospace Knowledge Diffusion

The formal part of the aerospace knowledge transfer mechanism relies on producer surrogates, information products, and information intermediaries to complete the producer-to-user transfer process. Although information intermediaries play a significant role in the diffusion of this knowledge, their contributions to the knowledge diffusion infrastructure are poorly understood. A strong methodological base for measuring or assessing the effectiveness of the information intermediary is lacking and empirical findings on the effectiveness of information intermediaries and the roles they play in knowledge transfer are sparse and inconclusive. The value placed on and the use made of the information intermediary and information organization have been the criteria used in determining the intermediary's role in transferring the results of federally funded R&D. In addition, the impact of information intermediaries is likely to be strongly conditional and limited to a specific institutional context.

In a study conducted for the U.S. Department of Energy, King and his colleagues (1984), using a value added approach, investigated the contributions that information intermediaries and organizations make to the value of information. First, they assume that information is a necessary commodity for conducting R&D. Second, they estimate that, if information were unavailable from libraries/technical information centers, information substitutes would be more expensive and potentially less effective. Hypothetically, if information were not readily available, less actual information use would occur and less value would be derived from information seeking, thereby increasing the fundamental cost of R&D.

DATA FROM THE AEROSPACE KNOWLEDGE DIFFUSION PROJECT

The existing federal STI transfer mechanism serves as the conceptual framework for the presentation of data on the interface between aerospace libraries (information intermediaries) and aerospace engineers and scientists (end users) in the aerospace knowledge transfer process. The data were collected from three mail surveys (each with an adjusted response rate of approximately 70 percent) conducted as part of the Project. A comparison of the behaviors and perceptions of these two groups in regard to the use of information technology further illuminates problems with the current supply side models of knowledge diffusion. It is further suggested that HPCC and STI policy initiatives should be pursued in tandem in order to diffuse R&D results more effectively.

The approximately 34,000 members of the American Institute of Aeronautics and Astronautics (AIAA) served as the study population for the first survey. The sample frame consisted of 6,781 AIAA members (one out of five) who reside in the United States and who are employed in academia, industry, and government. Systematic sampling was used to select 3,298 study participants. The study spanned the period from May 1989 through February 1990.

A list of U.S. and Canadian aerospace libraries served as the population for the second survey. This list was compiled from several sources, including the *Directory of Special Libraries and Information Centers* and the Special Libraries Association. To be eligible for participation in the study, each government or industry library had to hold aerospace, aeronautical, or related collections. The survey was conducted between May and August 1990. In all, 182 libraries responded to the survey.

Three groups in the academic aerospace community served as the population for the third study. The first group was academic engineering libraries.

Table 1. Characteristics of U.S. Aerospace Information Intermediaries—Academic and Industry Sector

Characteristics	N = 68 Academia %	N = 182 Industry %
Gender		
Female	66	71
Male	34	29
Years of library experience		
1–5	17	10
6–10	14	8
11–15	17	16
16–20	27	24
21–25	15	10
Over 25	11	32
Years in present position		
1–5	47	36
6–10	20	24
11–15	14	7
Over 15	19	33
Education		
BA/BS	81	41
MA/MS	31	16
MLS	88	60
MBA	3	2
JD	1	*
Ph.D	3	3
Professional (National) membership		
ALA	60	21
ASEE	27	2
ASIS	4	10
SLA	41	51
No (National membership)	7	15

**not asked*

The second group was faculty in aerospace engineering departments. The third group was students enrolled in a University Space Research Design capstone design course. The surveys were conducted between April and September 1990. Of the 70 eligible libraries, 68 returned a completed questionnaire. Of the 501 faculty surveyed, 275 responded. There were 640 student responses from 29 institutions.

Demographics

Data are presented for both the academic and industry intermediaries (see Table 1). Although the two groups have many similarities, there are some differences between them. In education, for example, there are differences in the percentage of respondents holding bachelor's degrees and master's degrees in library

Table 2. Use of Selected Computer and Information Technologies in U.S. Aerospace—Industry Sector

Information technologies	N = 1044 Percent of aerospace engineers and scientists using	N = 182 Percent of aerospace libraries using
Mature		
Audio tapes and cassettes	37	50
Motion picture film	25	19
Micrographics & microforms	61	73
Video tape	61	52
Fax/telex	92	74
Computer cassettes/tapes	41	27
Developed		
Teleconferencing	56	23
Video conferencing	23	12
Electronic data bases	55	74
Emerging		
Electronic mail	49	52
Electronic bulletin boards	27	31
Laser/video disk/CD-ROM	6	42
Electronic networks	41	43

science. Differences in professional (national) membership also exist among the two groups.

Use of Information Technology

The data in Table 2 are from the AIAA and industry library surveys; they depict differences in the use of information technologies (in this Project, information technology includes computer and communications technologies as well as nonelectronic mechanisms for information storage) by private sector intermediaries and end users. Thirteen information technologies were placed in three groups: *mature*, *developed*, and *emerging*. Mature technologies include videotape, fax, telex, micrographics and microfilms. Developed technologies include teleconferencing, video conferencing, and electronic databases. Emerging technologies include electronic networks, bulletin boards, and mail, laser disks, video disks, and CD-ROM products. Those who used at least one of the technologies in their work are considered to be users.

The data suggest that intermediaries are continuing in their role as passive disseminators of formal STI. Aerospace libraries are the predominant users of electronic databases and STI stored in laser/video disk/CD-ROM databases. Engineers and scientists, on the other hand, are the primary users of information tecnhnologies that facilitate informal communication (e.g., fax/telex, teleconferencing, and video conferencing) and the exchange of data (e.g., computer tapes) among knowledge producers and users. Electronic mail and bulletin boards are used by about equal proportions of intermediaries and end users. The data do not reveal whether these technologies are used within or between the two groups.

Industry end-users and intermediaries were also asked a series of questions regarding their use of NASA STI in specified electronic formats (see Table 3). In particular, they were asked how likely they would be to use computer program listings in electronic form. They were also asked how likely they would be to use online systems and CD-ROM products as replacements for NASA technical reports that currently are produced in paper and fiche. Those who selected "unlikely to use" these products in electronic format (data not shown in Table 3) were then asked why they would not use them.

Table 3. Perceptions About the Use of NASA STI in Specified Electronic Formats Within U.S. Aerospace—Industry Sector

Format	N = 975 Percent of aerospace engineers and scientists likely to use	N = 182 Percent of aerospace libraries likely to use
Computer program listings	55	14
Online system (full text and graphics) for NASA technical reports	56	40
CD-ROM system (full text and graphics) for NASA technical reports	39	31

The percentages combine 1 and 2 responses on a 4- and 5-point scale, respectively.

A majority of the end-users are likely to use computer program listings in electronic form. They are also likely to use an online system for NASA technical reports but not a CD-ROM system. Conversely, a majority of the intermediaries are unlikely to use all three items. The reasons given by the two groups who are "unlikely to use" are interesting. For the end-users, the primary reason is "prefer printed form," perhaps indicating an unwillingness to surrender personal access (however unwieldy) to mediated access, which they associate with current IR systems. For the intermediaries, "monetary cost" is the primary reason.

Respondents to the academic questionnaires were asked to indicate their use of seven information technologies presently being used or being considered for use in diffusing federally funded aerospace STI (see Table 4). As with the industry sample, electronic databases and CD-ROM products are being used primarily by academic intermediaries, and fax/telex is being used mostly by faculty. Overall use of electronic mail, bulletin boards, and networks is fairly low, with students exhibiting the least use. These data also reinforce the suggestion of the passive nature of the supply-side model of knowledge diffusion, in which intermediaries are chiefly responsible for providing access to the published record of STI. Current information technology, especially in the academy, is apparently not being fully used to facilitate interactive exchanges.

Faculty, students, and academic intermediaries were asked a series of questions regarding their use of NASA STI in specified electronic formats (see Table 5). In particular, they were asked how likely they would be to use existing products, such as NASA STAR, and certain potential products, such as an online system (with full text and graphics), for NASA technical reports. With the exception of their "likely use" of an online system for NASA technical reports, responses were mixed. A strong majority of academic intermediaries indicated their "likely use" of NASA STAR on CD-ROM; on the other hand, only slightly more than one-third of the faculty and students reported "likely use" of this product. Once again, end-users appear reluctant to consult STI bibliographic databases on their own. Faculty, in fact, seem disinclined to adopt new information technologies, in general. Policy initiatives aimed at the electronic provision of information should recognize that outreach and training will be needed to ensure the use of the proposed system.

Data from these three studies suggest that end-users are not completely satisfied by existing electronic information products and services. If services were better suited to the needs and capabilities of end-users, perhaps more of them would perform their own searches and more would indicate likely use of new electronic services. Increases in the number of end-users performing searches may free libraries to take a more active role in the knowledge diffusion process and the provision of value added information products and services. As a knowledge producer, NASA should consider the capabilities of information technologies for both formal and informal knowledge

Table 4. Use of Selected Computer and Information Technologies in U.S. Aerospace—Academic Sector

	N = 275		N = 640		N = 68	
	Faculty		Students		Libraries	
Information technology	Frequency of use, percent by	Do not have	Frequency of use, percent by	Do not have	Frequency of use, percent by	Do not have
Electronic data bases	17	6	25	12	72	4
Laser/video disk/CD-ROM	8	15	15	21	66	19
Desktop/electronic publishing	41	5	40	13	15	35
Electronic bulletin boards	13	5	6	16	18	18
Electronic mail	41	3	14	14	49	13
Electronic networks	30	38	15	14	32	18
Fax/telex	56	2	9	4	32	15

The percentages combine 1 and 2 responses on a five-point scale.

diffusion. It appears that information technologies will remain underutilized unless more appropriate products and services are developed.

CONCLUDING REMARKS

A holistic approach to technological innovation and economic competitiveness must be adopted at the federal level. The current supply-side policy emphasizing knowledge production and the trickle-down benefits associated with the funding of basic research and mission-oriented R&D are inadequate for developing a much needed United States technology policy. The current approach will simply not restore the U.S. to a more competitive footing with other industrialized countries such as Germany and Japan. These industrialized nations are adopting "diffusion-oriented" or "capability-enhancing" policies that increase the power to absorb and employ new technologies productively. U.S. technology policy efforts, on the other hand, continue to rely on a dissemination-oriented approach to the diffusion of federally funded STI.

The new approach to U.S. technology policy would be based on the assumption that the production, transfer, and use of STI is inextricably linked to successful technological innovation; that a positive relationship exists between federal attempts to stimulate technological innovation and federally funded STI; that the process of technological innovation is best served by a model based on knowledge diffusion; and that an STI transfer infrastructure, funded and coordinated as a partnership between American industry, academia, and the federal government, is required for the nation to become competitive in the global marketplace of the 1990s and beyond. Consequently, federal policy with respect to technological innovation and economic competitiveness would, by definition, include an STI component. In other words, STI policy would be tied to technology policy, not to a generic information policy instrument such as OMB Circular A-130 or to a particular information processing technology.

Table 5. Perceptions About the Use of NASA STI in Specified Electronic Formats Within U.S. Aerospace—Academic Sector

Format	N = 275 Faculty %		N = 640 Students %		N = 68 Libraries %	
	Likely to use	Don't know	Likely to use	Don't know	Likely to use	Don't know
NASA STAR on CD-ROM	36	33	38	44	74	6
Full text of NASA technical reports on CD-ROM	51	23	55	27	50	7
NASA computer programs listings on CD-ROM	32	27	44	29	29	16
NASA numerical/factual data on CD-ROM	29	26	46	29	47	13
NASA photographs (Images) on CD-ROM	28	25	50	25	26	18
Online system with full text and graphics for NASA technical reports	48	21	60	23	49	10

The percentages combine 1 and 2 responses on a five-point scale.

Such an approach must recognize the need to maximize the diffusion of federally funded STI and to coordinate federal STI activities using a mechanism similar to the now defunct Committee on Scientific and Technical Information (COSATI). A strong technology policy would commit the United States to building and maintaining a technology infrastructure that includes an STI transfer component based on a knowledge diffusion model. This model should have an activist component that emphasizes both domestic and imported STI, and it should be responsive in a user context. The most recent policy initiatives focus on the use of information technology to disseminate federal STI. Unfortunately, the capabilities of information technology to transform knowledge diffusion from a passive to an active process will be lost if the underlying model of diffusion is not changed. Furthermore, the system will remain passive if systems are not designed so that end-users can easily exploit them for both formal and informal communication and can perform highly interactive, problem-oriented searches that are based on more advanced IR mechanisms.

U.S. technology policy should view the structure, organization, and management of STI as a strategic resource. The need for more frequent and more effective use of STI characterizes the strategic version of today's competitive marketplace. STI policy should also reflect this same strategic vision for several reasons. Information technology is making the same STI available at the same time to all competitors. The marketplace is increasingly characterized by a growing number of stakeholders that are constantly changing. This implies that a broader array of STI will be needed for decision making and that simply providing retrieval and access without providing interpretation and analysis is meaningless. The need to provide STI interpretation and analysis is critical because less time is available for making decisions and the half-life of information is getting shorter (Barabba and Zaltman, 1991). This role is one that information intermediaries should adopt and one in which they could be aided by information technology. Electronic mail, bulletin boards, and file transfer provide mechanisms for more efficient and effective exchanges—both formal and informal—among knowledge producers, intermediaries, and knowledge consumers.

For the practicing sci/tech librarians who serve as information intermediaries, there is another open question that is important to answer: who will build and manage the new intelligent information retrieval systems? Hopefully, the information science component of the sci/tech library profession will play a central role in their design, construction, and management. However, the profession must overcome several important and fundamental impediments before it can be important player in the development of intelligent databases. Information scientists must rethink many of their current practices and change many of their procedures. What is most urgently needed in the profession, however, as Dougherty (1990) notes, is "a dramatic break with the past" coupled with "new initiatives that will enable [sci/tech] librarians to make fuller use of information technologies and the talents of library professionals."

The need to break with the past is not mere rhetoric. This break requires a new paradigm for structuring, organizing, and managing STI that allows for the retrieval of ideas; emphasizes sci/tech librarians' interpreting and analyzing information rather than accessing and retrieving documents; and enables information scientists to play an active and central role in the design, construction, and management of intelligent STI knowledge-based databases using expert systems. Breaking with the past is never easy, however. The new paradigm may necessitate a complete restructuring of library and information science education, "support of basic information science, including research leadership in the field, and constant self-renewal through some drastic form of continuing education, e.g., joint commitment by school and student to lifelong cyclic return to the school, following the first degree"(Heilprin, 1991). To do less, according to Heilprin, will "probably lead to [the] absorbtion of functions and personnel of the [sci/tech] library by other, more competitively adaptive information communities."

Sci/tech librarians have been educated and socialized to maintain, care for, and love the library and its enormous collection of documents. Since so much of the daily operation and activity of today's sci/tech libraries revolve around inventorying, housing, and maintaining the collection of documents, these libraries have inevitably been more concerned about preserving the collection than in providing access to it. As Heaps (1978, p. 1) has stated, the needs of the traditional library "led to the development of standard procedures for manual cataloguing, use of card indexes, bibliographies, and the circulation and ordering of books, journals, and reports." As a natural result, "the traditional library was oriented more to managing the things which carry information than managing information as if it were a resource."

Although it is easy to point out obstacles that will prevent information scientists from participating in the development of intelligent STI retrieval systems, it is important to note that they also possess the type of skills that would qualify them to work as knowledge engineers. The term "knowledge engineer" was first coined by Edward Feigenbaum in 1977 to describe the person who would be responsible for identifying pertinent information, developing a knowledge framework through a combination of representation and inference, and implementing this framework using software tools (Feigenbaum et al., 1988, p. 266). The skills needed by the knowledge engineer include a solid working knowledge of systems design and "a fairly high degree of computer literacy," in addition, the future knowledge engineer must possess "a fairly wide range of skills, many of which are behavioral in nature" (Beerel, 1987, p. 129).

Clearly, many information scientists already have most of the skills that a knowledge engineer would need. One fact is certain: intelligent databases will be developed in the near future, and they will offer the kind of context-sensitive access that will transform Bush's visionary Memex into a practical research tool. What is less clear, however, is the role that information scientists will play in the development of new information technologies. Hopefully, they will seize the opportunity and adapt their professional and educational institutions so that they can take full advantage of the enormous opportunities offered by new technology.

Unfortunately, library and information science education reflects the same uneasy mixture of traditional values overlaid with a soupçon of information technology that characterizes so much of the professional life of information scientists. A large part of the curriculum is designed to turn out students qualified to operate document warehouses, while a set of specialized courses that are usually introductory in nature, attempt to turn out information professionals equipped with the skills needed to take advantage of the new information technologies. In a very real sense, library and information science education is struggling, perhaps unsuccessfully, with an attempt to amalgamate two incompatible and competing paradigms (Cronin, 1991).

In conclusion, it is clear that we need new paradigms for the knowledge diffusion process and for the role of information intermediaries. Also lacking are empirical data that would guide the development of new information systems and services. Additional knowledge is needed to help formulate an appropriate model for developing a holistic and conceptual technology policy. Policy research is required to provide a better understanding of the process of technological innovation and the relationship between STI and technological innovation. A clearer understanding of the process and the relative effectiveness of the existing federal STI transfer mechanism is also needed. Of particular importance is a better understanding of the information intermediary and end-user interface. Such information is needed before recent federal initiatives in high-speed computing and networking will meet their full potential for increasing research productivity and speeding the process of technological innovation.

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