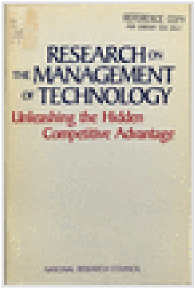

Research on the Management of Technology: Unleashing the Hidden Competitive Advantage (1991)

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RESEARCH ON THE MANAGEMENT OF TECHNOLOGY: UNLEASHING THE HIDDEN COMPETITIVE ADVANTAGE

Steering Group for Management of Engineering
and Technology
Manufacturing Studies Board
Commission on Engineering and Technical Systems
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

At the request of the National Science Foundation, the Steering Group for Research on Management of Engineering and Technology was created by the Manufacturing Studies Board of the National Research Council to discuss mechanisms for enhancing university-industry collaboration in the area of management of technology (MoT), focusing on the access of academic researchers to technology management processes in industry.

The steering group met on three separate occasions. At the first meeting, it determined that its original scope was too narrow, since improving the access of researchers to technology processes would not, in itself, improve the practice of MoT or help U.S. competitiveness. The steering group determined that it could better use its expertise to address the larger issues of:

- identifying useful ways to perform MoT research that can benefit industry and the U.S. economy and
- discovering mechanisms that will result in industry adopting existing and new MoT techniques and applying MoT research findings.

The second meeting featured presentations by experts from industry and academe who described examples of university-industry collaborative efforts with specific emphasis on MoT. The presentations were followed by discussions focusing on mechanisms to:

- provide guidelines for conducting usable research on MoT;
- establish new and enhance existing mechanisms to transfer and adapt the knowledge developed about MoT to a broad set of users in a timely manner; and
- promote MoT as a high-priority area for industry, university, and government support.

Following the second meeting, the chairmen drew up a report outline from which they and other steering group members drafted chapters of the report. Following two rounds of revisions by the entire steering group, and a final review meeting, this report emerged.

This report was made possible by many people who work directly and indirectly on the management of technology. The study was conceived and planned by Fred Betz of the National Science Foundation, Richie Herink of IBM Corporation, and Kerstin Pollack of the National Resarch Council. In addition to the committee members, experts from the following companies and academic institutions contributed to a greater understanding of issues in the management of engineering and technology: Technovation, United Technologies, Oak Ridge Associated Universities, Harvard University, Massachusetts Institute of Technology, New Jersey Institute of Technology, University of Michigan, and University of Pittsburgh. Main staff support was ably provided by Paul Shawcross, Ted Jones, and Verna Bowen.

Alistair M. Hanna and Albert H. Rubenstein
Cochairmen, Steering Group for Research on
Management of Engineering and Technology

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Executive Summary

Faced with crowded world markets and intense competition for market share, U.S. companies are becoming increasingly dependent on innovative process and product technologies to develop and market new and improved products and services. To an everincreasing extent, these advanced technologies are a pervasive and crucial factor in the success of private corporations, the effectiveness of government operations, and the vitality of national economies. The United States has dedicated immense resources to the discovery and development of advanced technologies but has paid relatively little attention to how technology can be managed more effectively. According to the National Science Board's *Science and Engineering Indicators*,[1] U.S. industry spent $64 billion on research and development in 1989, yet less than $1 million was spent in studies to learn how to manage this huge effort more effectively. In addition to its magnitude, the fast pace of technology change has made the effective management of technology all the more difficult in achieving corporate strategic goals, yet all the more critical. Unfortunately, industry and academe have a poor understanding of the management of technology (MoT) and have made very little progress in recent years, while technological competitiveness has grown in importance to individual companies and to our nation. For this reason, effective technology management is vital for our national interest.

This report outlines a research agenda, for industry, universities, the National Science Foundation, and the National Research Council, that addresses the need to increase rapidly the effectiveness of technological factors such as research, development, implementation, engineering, and manufacturing. It is crucial for these factors to be managed skillfully to maximize competitive advantage from both a business and a technological perspective. This is the domain of MoT, a critical factor for assuring success in today's business world.

This report builds on the 1987 NRC report, *Management of Technology: The Hidden Competitive Advantage.*[2] That report made a strong case that:

- technology can provide a firm with a critical competitive advantage in the global marketplace,
- many U.S. corporations have lost their leadership positions in technology and are experiencing difficulty competing in the global marketplace, and
- the results of academic research on MoT have the potential to help halt and reverse this decline.

The 1987 report identified a number of ways in which industry and universities could work together to address MoT issues, defined a problem-driven research agenda, and suggested that a continuous and cumulative effort be undertaken in which researchers could work with industry and government to begin building a comprehensive, conceptual framework of MoT practices.

Overall, progress since the 1987 report has been mixed. The university/theoretical side of the field has grown slowly, while academe and industry have not specifically addressed many of the topics that were suggested in the 1987 report; the communication gap between academe and industry remains large; and the limited results of research on MoT have not had a significant impact on improving America's competitive situation. No substantive support has appeared among the federal agencies for MoT research, and support of MoT research by industry is sparse.

KEY RESEARCH ISSUES

A large number of research "needs" in MoT have surfaced. In order for research on these needs to be beneficial, it must be conducted and supported in such a way that the outcome is usable by industry. "Useful research" is defined as research that

- makes use of appropriate resources and information from industry and academe and
- produces results that are useful to academe and, more importantly, to industrial practice.

Two fundamental impediments to conducting useful MoT research are (1) lack of funding for and awareness of MoT research and (2) problems relating to university-industry research relationships in MoT. While greater cooperation between industry and academe is clearly needed, the two groups often have conflicting motivations and needs for research projects. Universities often discourage academics from pursuing action-oriented (applied) research, thus constraining their understanding of broad industrial systems. For numerous reasons, there is also a tendency for industry to give token support to, and eventually to lose interest in, the research it *does* fund. Senior managers seldom read the reports produced by academic research and frequently find them difficult to evaluate because of academic jargon. Even when the results of MoT research are well communicated and potentially valuable to managers, it is often difficult for companies to incorporate them into daily operations or use them to manage technology more effectively. These difficulties are often due to the research being both too narrowly focused and outdated, addressing past rather than contemporary issues. A more basic problem is how to overcome the inherent difficulties of reaching the correct audience, thus ensuring that MoT research results reach the businesses that need the results most.

These barriers have prevented industry from receiving much benefit from the limited university MoT research that does take place. As a result, the normal cycle (as outlined in the 1987 report) of research feeding industry and government, which then support further research, is not occurring.

POSSIBLE SOLUTIONS

Various mechanisms can be used to overcome barriers to effective MoT research and implementation. Universities can contribute to these mechanisms by improving their role in research by encouraging interdisciplinary research activities, programs, and curricula and by broadening their research and teaching performance reward systems. The educational role of universities could be better used to foster communications between university departments and between universities and industry, to develop and support additional graduate degree programs in MoT, and to develop appropriate professional-level continuing education programs.

Mechanisms to enhance industry's role in MoT include rewarding people wishing to take cross-functional assignments or engage in developmental experiences in academe, incorporating the support of MoT research into business objectives, and specifically targeting research funding for MoT. Possible joint university-industry mechanisms include collecting, codifying, and making available information on successful MoT practices to industry and academe; establishing a national case library for MoT practices; and establishing MoT research consortia modeled after successful programs in other areas. The distance between MoT research and practice is too broad for improved research alone to close the gap and enhance industrial practice and technological competitiveness. The transfer, application, and implementation of generalizable MoT principles must also be addressed.

The government can support MoT research in a number of ways. The

National Science Foundation is urged to create a central focus for coordinating and focusing research on MoT by forming and funding a Division for MoT Research within the Directorate of Engineering; convening a blue-ribbon panel to set the mission, objectives, and funding for MoT research; and supporting new and expanded centers of excellence for MoT. These centers would perform basic and applied research on MoT and related subjects, train both degree candidates and practitioners, and engage heavily in dissemination of MoT research results and reports of effective practice. The National Research Council is urged to provide the field of MoT with direction and guidance by establishing a sustained oversight activity on the management of technology to (1) encourage the dissemination of MoT research results, (2) promote improved MoT research practices, and (3) help focus national attention on this vital topic.

The Importance of MoT

WHAT IS MANAGEMENT OF TECHNOLOGY?

In the 1987 NRC report *Management of Technology: The Hidden Competitive Advantage*, management of technology (MoT) was defined as linking "engineering, science, and management disciplines to plan, develop, and implement *technological* capabilities to shape and accomplish the strategic and operational objectives of an organization" (p. 9). The field is too young to attempt a rigorous definition that will provide firm inclusion and exclusion criteria, let alone to attempt a rigorous taxonomy that provides a structure for the field in terms of exhaustive discrete categories that are mutually exclusive. For the present, the steering group has taken a broad view of the field with emphasis on inclusion rather than exclusion, allowing wide latitude for the inclusion of activities by researchers and practitioners so that eventually the "key" issues and relevant research topics can emerge.

IMPORTANCE TO INDUSTRY

Conventional systems for technology development have proven insufficient to keep U.S. industry competitive in a rapidly changing business and technology environment. There are obvious reasons why a more innovative approach for managing technology is needed. First, evaluating technological options and managing technology implementation and operation are becoming more difficult, especially for technologically unsophisticated executives. Second, escalating costs of creating and using new technologies, reaching billions of dollars in some industries (e.g., jet engines, automobiles, computers, and integrated circuits), have changed the scale of potential risks and rewards; in many industries, effective technology management has become a "bet the business" proposition. Third, managing technology properly has strong economic consequences, which are heavily dependent on the quantity and nature of the inputs *and* the way the inputs are applied and managed.

There are many areas in which improved technology management practices could benefit different types of industry. Managing technology in the chemical industry is significantly different than managing it in electronics or aircraft engines; however, the steering group believes that there are generalizable practices in MoT, just as there are in marketing or finance. These practices must be adapted to such industry-specific factors as competitive environment, core competencies, and available resources. Examples of developing technology management practices that have been adopted and adapted to the needs of U.S. industry include such techniques as flexible manufacturing and quality function deployment.

Some of the major problems that exist in MoT would be more manageable if a set of successful practices were identified and made known to industry. Illustrative problems include the following:

• Significant investments in projects to develop new technologies have a long lead time before new or improved products or processes are realized. When the improvements in technology and product sought by these projects are radical rather than incremental, the projects often cannot be clearly described in terms of the specific steps that are required or the exact technological result that will be achieved. Because new technologies are often costly and difficult to quantify in terms of expected payoff, they are difficult to convey to nontechnical people and may not be directly linked to company strategy. As a result, many high-level executives—who are not comfortable with technological issues—tend to discount the value and importance of significant and sustained investment in technology, thus blocking the emergence of a clear strategy for managing it. Instead, they tend to rely on momentum-based rules of thumb,[3] causing some firms with limited opportunities for improvements to vastly overspend, while others with many opportunities or potential competitive threats to grossly underspend.

• Corporations are inherently motivated to maximize their returns from investments in new technology, but clear criteria remain elusive. The "right" approach for each firm depends on its overall business strategy and on the type of technology. There are no hard and fast criteria to determine under what conditions to license technology, to whom, and at what price. Historically, U.S. companies have protected their technology through intellectual property rights in order to reap the monopolistic rewards of proprietary technology for the maximum amount of time. While this is still an appropriate approach in some industries (e.g., chemicals), others benefit more from generous licensing of their technology (e.g., in order to build industrial standards or position themselves better in a market). Still others may take a mixed approach by restricting licensing to foreign firms for use in foreign markets.

• The benefits of technological advance go beyond direct financial return, but few companies have a capacity to evaluate the strategic advantages that technological investments can offer.

—Typically, technological investment is undertaken incrementally. As such, the investment is composed of a series of discrete decisions that are contingent upon the success of earlier investment decisions. Too often, managers do not have the vision to see the benefits of alternative investment options, and potentially attractive technological investments are lost or not continued as a result.

—Often technological investments are made in pursuit of a proprietary product or service. It is very difficult to predict accurately the value of such a proprietary position or determine how long it will remain proprietary. Consequently, many promising technological investments are not made because the opportunities created by such a dominant situation are not of a proprietary nature (building market share, penetrating new markets, increasing production turnover, etc.) and are not well understood.

• Many U.S. companies do not know when to spend heavily on technology research and development and when to hold back on spending. The amount of progress or profit achieved in relation to the resources expended can vary greatly during a technology's life cycle; however, most measurement systems often do not capture such fluctuations very well. There are times when investing money in research and development can achieve a major competitive edge in terms of product performance, but ascertaining these optimal times is difficult.

• Technology transfer is another area of concern in the management of technology. Blame for the problem can be divided between the "passer," who attempts to transfer a less than fully developed technology or product, and the "receiver," who has done little, if anything, to prepare for its implementation and use. Managers must have some way of determining which in-house technologies are of value to other departments within their company or which are of value outside the company (sale or licensing). How technologies can be modified to enhance transferability without sacrificing performance or cost effectiveness is an issue for further study in MoT.

• Development time for new products is often longer in the United States than in other countries.[4] This situation can be partially blamed on the approach to managing technology in the United States.

— Many firms do not perform enough research before embarking on development. As a result, development efforts cost more and take longer.

—Poor planning of the development process makes it impossible to schedule the required work efficiently to overcome key problems at the appropriate time and rate.

—Poor communication between the various departments and functions within a firm prevents them from progressing in parallel toward a common goal.

—Poor understanding of the effects of team size and composition on work effectiveness leads to inefficiencies and conflicts that may actually slow the pace of development; twice as many people often cannot do the work in half the time. And managers lack experience and guidance in the leadership of multifunctional teams.

- There are numerous problems associated with managing internal company resources, especially where large numbers of people and highly sophisticated technology are spread across several departments and continents. Issues of infrastructure and design often come into play as operational and working procedures change without being defined or properly understood.
- Companies tend to bank on major technological advances, while undersupporting smaller projects. There is a need for constant incremental investment in evolutionary technological development and application in addition to the need for major capital investment projects relating to breakthrough technology and its application.
- Advances in process technology can prove as valuable as advances in product technology, yet many companies underinvest in process technology.

SIGNIFICANCE FOR U.S. COMPETITIVENESS

It is clear that U.S. industry faces many significant problems in managing technological investments. Until solutions to these problems are developed and accepted broadly, or, at a minimum, until they are recognized by company managers and solutions are attempted, it is unlikely that U.S. competitiveness can be significantly improved against competitors who have a superior approach to MoT. The management practice literature currently has little salient advice to offer technology managers beyond broad generalizations, such as "quality is free" or "parallel engineering can speed up development." Further, "war stories" on technology management are often too highly specific and narrowly applicable to be helpful to other technology managers.

Although MoT is critical to competitiveness in low- and medium-technology areas, it is generally agreed that U.S. firms are not as competitive today as many of their rivals in high-technology areas.[5] Over the past several years, each of the conventional excuses given for the inability of U.S. industry to compete has been challenged effectively. These excuses have included the low value of the dollar, high interest rates, cultural homogeneity, and restrictive trade practices. The emerging dominant view, with which the steering group agrees, is that much of the problem lies with management. It is extremely important that the critical role that management, and particularly the management of technology, plays in national and corporate competitiveness be recognized.

Characteristics of the current environment include

- there is as yet no generally accepted set of practices for MoT;
- if industry and academe continue on their current paths, it is highly unlikely that either academe will stumble into a winning method for MoT or that industry will significantly improve on its record of competitive decline in technology-based products; and
- the haphazard copying of Japanese approaches is unlikely to work for U.S. corporations and continues to place U.S. industries in a follower role.

Long-term success is thus dependent on taking initiatives that will focus academic research on relevant MoT issues, convince management of the importance of MoT as a significant component of competitive strategy, and build a solid partnership between research and practice, providing worldwide leadership in the management of technology.

The Status of Research on MoT

THE STATUS OF MoT IN 1987

The 1987 NRC report made a number of observations about the status of MoT.

• Education and research efforts were fragmented and uncoordinated. The field received little research funding, few faculty were involved, and there were relatively few well-structured educational programs. The most successful educational mechanisms in MoT appeared to be short courses and mid-career programs for middle managers.

• Corporate emphasis on MoT was uncommon, but a few large, technology-based corporations operated in-house training programs in related areas, and some managers were sent to the limited number of university courses and seminars available on aspects of MoT.

• Industrial leaders were skeptical of the applicability of academic research and education in MoT to the needs of their organization; many academics were skeptical about the value of MoT. These academics generally believed that education and research in traditional academic disciplines were more useful than education and research specifically focused on MoT. Some also resisted the idea of collaboration among universities or between business and engineering schools, although a few schools had successful joint programs or courses in MoT.

The report highlighted several critical areas needing improved research input, including

- integrating technology into the overall strategic objectives of the firm;
- getting into and out of technologies faster and more efficiently;
- assessing and evaluating technology more effectively;

- determining the best way to accomplish technology transfer;
- reducing new product development time;
- managing large, complex, and interdisciplinary or interorganizational projects/systems;
- managing the corporation's internal use of technology; and
- leveraging the skills of technical professionals.

In addition, the report identified ways in which industry and universities could work together to address these issues. It suggested that a continuous and cumulative effort be undertaken to build iteratively toward a comprehensive curriculum and conceptual tool kit for MoT. In this effort, progress in research would add content to the curriculum and drive the development of needed management tools and insights. These tools would then be tested in the "laboratory" of actual experience and disseminated to industry and government, inducing them to fund further progress in MoT research.

DEVELOPMENTS SINCE THE 1987 REPORT

Overall, the news since the 1987 report is mixed. The university/theoretical side of the MoT field has grown through degree programs. The new Ph.D. graduates are interested in doing empirical as well as theoretical research in the field, but there are too few of them. Steps taken jointly by industry and academe have resulted in the establishment of approximately four chairs and six academic degree programs in MoT, approximately five MoT research centers, and the provision of both funds and people to support selected initiatives by individuals and universities.[6] Additional major thrusts are in the early or planning stages.[7]

Although it may be too early to expect them, these limited initiatives have not significantly improved the competitive situation thus far, and no comprehensive set of practices on managing technology seems to be emerging. The 1987 initiatives were intended to help develop a commonly held and credible vision of the role of technology in the economic success of industrial firms which, to date, is still evolving. The broader academic community has not specifically addressed many of the topics that were suggested in the 1987 report, and the communication gap between academe and industry remains large. One of the biggest problems in the field is the lack of coherent and consistent research support for MoT from either industry or the government.

The 1987 MoT report recommended that "the NSF, acting as a catalyst, and the DoD and NASA, as leading mission agencies and users of technology, should support research in MoT that would identify important issues and needs in this area and begin to define solutions to those needs" (p. 28). The report recommended several support mechanisms, including providing grants for individual academic researchers, funding small group research, providing financial support for master's and doctoral students in specialized MoT programs, supporting doctoral fellowships in MoT, and establishing one or more cross-disciplinary research centers in MoT.

Limited results have been realized from these recommendations. Individual universities have made some progress in initiating proposals for funding their MoT research interests. In addition, the 1987 NRC report drew international attention to the MoT issue, especially in Canada, Europe, and the academic community in the United States. While the resulting American support of MoT remains fragmented, Canada provided McMaster University $10 million (U.S.) and the European Economic Community provided $15 million (U.S.) for technology management research.

Industry's record for funding MoT research is mixed. Although several large grants were given initially by industry to establish research centers and chairs in manufacturing technology, some of which included MoT, they also limited internal funding for research on MoT. Recently, many firms have also reduced their funding of university research of this type. Where funding has been made available, few of the grants to establish or support centers of excellence in manufacturing have included funds earmarked for research on MoT. Notable exceptions to the history of support are in the area of managing information and telecommunications technology and in the general area of service sector productivity and competitiveness. In these two areas, technology is recognized as a key element for effectiveness and survival and the management of that technology is considered critical.[8]

The formation of this steering group—the second NRC study on MoT—is an encouraging sign that the topic is not just a passing fad and that serious attention is being paid to MoT by the National Science Foundation, the NRC, industrial managers, and academic researchers. The output and follow-up activities of this committee should contribute significantly to increasing levels of awareness, thus providing direction in addressing some of the issues and constraints mentioned in the 1987 report.

THE CURRENT STATUS OF RESEARCH IN MoT

It is clear from the work of this committee, its predecessor committee, and the judgment of the participants that the current state of knowledge on managing technology effectively is not adequate to assure the technological competitiveness of many U.S. industrial sectors now or in the future. However, there are some noteworthy indications that limited progress is being made toward improved MoT understanding. The challenge is to maintain this progress and increase its impact.

Segments of the desired knowledge base do exist in the practice of individual organizations and industrial sectors in the United States, Europe, and Japan. In addition, systematic research that could contribute to a more structured and credible knowledge base and improve the management of technology projects, programs, and organizations is being performed by independent researchers in some large universities, industrial firms, and other organizations. Examples of the kinds of management practice that could emerge from MoT research are innovations such as just-in-time inventory control, computer-integrated manufacturing, activity-based cost accounting methods, and parallel engineering.

MoT is not recognized by most firms as a specific issue, research topic, technical or management discipline, or even a matter to be addressed systematically. Hence, executive managers do not consider managing R&D, manufacturing, information and telecommunication systems, and engineering as any different from other aspects of a firm's business, except in cases of crises such as a significant problem in a new product, manufacturing facility, or process. Except for such crises, managers of these activities are generally left on their own to design and operate their technology functions according to their own experience, conventional "wisdom," literature on management practice, gut feel, the experience of other managers, or by trial and error. Apart from a few firms that encourage their technology managers to attend training programs or to conduct research and publish, few attempts are made to draw from the limited extant theory and generalized knowledge about MoT.

As a consequence, there are almost no industrial programs of systematic in-house research on managing technology. The normal scientific model, which would lead to establishing in-house groups to study, adopt, adapt, and implement the results of technology management research, is not being followed in the case of MoT. In other words, technology managers do not generally conduct "R&D" on technology management, although significant effort is devoted to the technology itself. In essence, the cart is put before the horse. U.S. industry spent $64 billion on research and development in 1989,[9] *but certainly less than $1 million was spent in studies to learn how to manage this huge effort more effectively.*

The lack of an internal research capability in "research on research" leads to an adoption, adaptation, and implementation gap as well as a cutoff of possible contributions to the literature and the knowledge base about MoT from industrial firms. Without active researchers—especially *applied* researchers—there is no one to report systematically and credibly the experiences and perceptions of firms with regard to MoT. Hence, many potential case studies and more general insights are lost.

In universities, some effort is under way to improve the quantity and quality of research on MoT that involves gathering, systematizing, testing, and validating the fragments of knowledge that come from industrial practice and systematic academic research. Many journals, conferences, bibliographies, and other dissemination media are available, and there is currently no problem in publishing good, credible research or in finding a forum for presenting research results.[10] Bibliographies in different areas of the field[11] also provide sources for locating recent research and dissertations. Publication media and bibliographies do not constitute a barrier to progress in the field, and the growing *volume* of articles and books on various aspects of technology management is encouraging. Nor is there a lack of conferences and seminars, at which scores of speeches and papers are generated and presented each year. Some critical aspects of MoT, however, receive little attention.

If the practice of managing technology is to be improved through the application of research on the MoT process, the research must, in addition to being scientifically credible, be action oriented and relevant to industrial management. Since MoT is not a basic discipline but an interdisciplinary and applied field of research, MoT research should not be judged by its contribution to pure theory. The key criteria should be relevance and rigor: relevance vis-à-vis the needs of industry, and rigor in the degree to which the results are generalizable beyond a specific problem in specific circumstances and robust enough to withstand the tests of replicability, application, and evaluation. Using these criteria, current MoT research displays several weaknesses.

One problem is rigor. Much of the research and many of the papers reflecting individual experience with MoT fall short of the attributes needed for entry into a systematic or "scientific" body of knowledge. Definitions of terms, methodologies used for data collection, inference methods used for drawing conclusions, and formats for presenting results fall short of contributing significantly to such a body of knowledge. This retards efforts to synthesize results into theories or principles useful to managers.

Another problem is that much of the research that is published never reaches managers who might take advantage of it. Articles in many academic journals are couched in a scholarly jargon and thus are difficult for lay people to comprehend. Furthermore, since managers of industry do not read most academic journals, even research that is written in an understandable form is not often put into practice. Faculty evaluation and promotion, however, rely heavily on publication in such academic journals. As pointed out in a recent *Business Week* article,[12] academics have too little incentive to publish in practitioner-oriented journals.

In addition, the choices of research topics by faculty members and their students often do not relate to the kinds of MoT problems that industrial and other practitioners see as relevant and necessary to enhance their organizations' technology management practices. The choice of dissertation topics is often strongly influenced by the research interests of thesis advisers, which include what is fashionable and publishable at the moment and what kinds of research can be done with limited access to "real" organizations and without significant funding. These factors have led to research and dissertation topics that are often fairly abstract, mathematical, inexpensive to perform, and that do not require "real data." As a consequence, decision makers and practitioners lack a broad, long-term perspective; are denied generic approaches and solutions offered through the aid of a systematic body of knowledge; and tend to think of technology management in terms of their individual, specific, and urgent problems.

Conducting MoT Research

CONDUCTING RESEARCH USEFUL TO BOTH ACADEME AND INDUSTRY

Management of technology does not exist as an identifiable management discipline, like accounting or marketing. MoT is only partially realized in such recognized fields as management of research and development, engineering, and management information systems. To some degree, it is also imbedded in all of the functions of any product- or service-producing organization. This pervasiveness throughout an organization is what makes MoT so difficult to identify and codify. Furthermore, managing the technology of a steel mill may be very different from managing the technology of an aircraft engine company, for example. There are numerous aspects of MoT that are more of an art than a science, yet that play a significant role in enabling an organization to compete successfully in the global marketplace. How these activities are managed varies from firm to firm and from organization to organization within a firm. The effort to make these activities explicit, generalizable, and broadly applicable in practice could have great rewards.

Technology management can be thought of in five major categories.

1. *Managing the development of technology.* This category includes managing the product development process throughout the entire life cycle from idea to development, to engineering, to marketing, to end of life. It also includes managing the overall innovation process.

2. *Managing technologically complex processes.* Managing highly automated factories and telecommunications networks requires a different kind of management technique than managing traditional labor-intensive operations.

3. *Using technology for competitive advantage.* This includes applica-

tions such as the development and use of airline and hotel reservations systems, computer-aided design and manufacture, on-line banking systems, expert systems, robotics, automation, or other technologies that give a firm a competitive edge. These applications attest to the successful integration of technology and business strategy.

4. *Interactions between technology and the organization.* This includes problems with integrating technology into the operations of the organization and the process of having technological solutions accepted by an organization.

5. *Social consequences of technology.* This category embraces the impact of technology on society and on mankind.

In considering the criteria that may be used for evaluating (and monitoring) research in MoT, the dual objectives of such research must be taken into account. These are (1) the *academic* objective of increasing knowledge about a complex phenomenon and providing scientifically credible reports of research and (2) the *industrial* or other user's objective of obtaining credible and usable information quickly to help in making decisions, solving problems, and managing operations.

This dual set of objectives complicates the process of evaluating the research process and its results. For purely *academic* or "basic" research, the criteria are straightforward. The process must be "transparent" so that other researchers can clearly follow the steps taken and decide whether the conceptualization, study design, data collection and analysis protocols, and other aspects of the methodology are credible and replicable. The results must be communicable and subject to tests of the data and the inference procedures used to draw findings from the data. In a complex or hybrid new field, there is often temporary tolerance for unorthodox methodology and even for "far out" inference methods, but there is little tolerance for entirely idiosyncratic methods of data collection, analysis, or inference that cannot be understood or replicated. Timeliness and practical usefulness are not dominant criteria, except when timely publication in some fields is crucial for the careers of researchers. Usefulness to people other than researchers—such as practitioners—is not a necessary condition for scientific acceptability and, in fact, is sometimes disdained by scientific colleagues. These rather strict criteria, and others related to a given field (e.g., "elegance of a formulation"), are not likely to dominate a new, hybrid, and practice-oriented field such as MoT (compared to traditional disciplines such as chemistry, physics, or mathematics), except where the promotion, tenure, dissertation, or scientific reputation of the researcher is at stake.

The criteria from the *managerial* application side are equally clear, although quite different. "If it works, makes sense, and is timely, it's good research" represents a common view of management and other fields of practice. Unfortunately, face validity and degree of agreement with priorheld beliefs and attitudes (because these aid in usability) often dominate the manager's evaluation of such research. Originality, the cumulative nature of the findings (e.g., focusing on the aggregate value of research rather than on individual research investments), and communicability in the scientific sense (e.g., publication in the open literature after peer review) are not salient criteria in the evaluation of such applied research. If MoT requires a major departure from past practice (one or several paradigm shifts), management will likely have difficulty valuing and incorporating this knowledge.

Both communities share a desire that research be "cost effective" or efficient, by some definition. In academe the cost/effectiveness ratio is often set by the amount of funding available to do the research and the likelihood that one or more publications will result. In industry the cost/effectiveness ratio is typically the "bang for the buck" that reflects the payoff from solving a real and possibly urgent problem in a timely fashion and with a good ratio of benefits achieved as compared to the cost of the research. In general, industry is usually preoccupied with the short-term industrial applicability of results, and academe is usually preoccupied with the short-term publication payoff.

Given these divergent sets of criteria, it is not easy to visualize a "portfolio" of MoT research projects that would fully satisfy both academic and industry needs or expectations. Even academic research projects that situate themselves at the applied end of the spectrum will typically not get top scores according to industry standards—internal research will typically be more closely tuned to the business's needs. The best hope for achieving a reasonable level of agreement is to undertake projects jointly at the early stages of the "R&D/innovation" process for MoT, itself, making the effort to select and develop a set of projects that, if and when they yield results, are likely to satisfy at least an acceptable portion of the key criteria of both parties. This can only be accomplished by bringing together knowledgeable industrialists and academics. Out of such associations, an agenda for research could be developed that could meet the needs of both groups. Given that starting point, careful monitoring is needed to keep the projects progressing in a fashion that satisfies both parties' needs, such as timeliness, relevance, scientific credibility, and face validity. As in the science/engineering, science/medicine, and other basic/applied fields, perfect matches are rare and continual adjustments must be made to keep the projects "on track" and the sponsors, users, and researchers satisfied.

THE NEED TO FORGE CLOSER UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS

There is plenty of room for all interested parties to contribute to the wide spectrum involved in MoT research. Certain topics and approaches are best suited to individual faculty members and their graduate students. Others

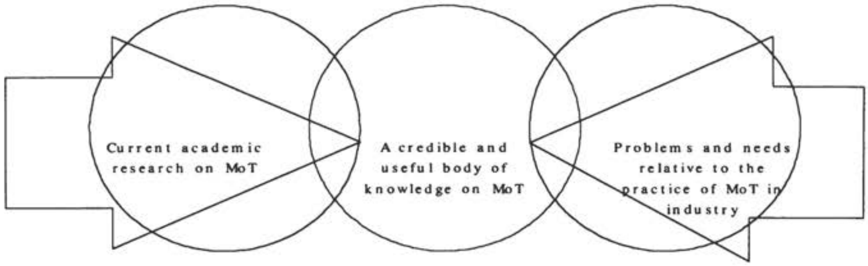

Figure 1. The gap between current academic research on managing technology and industry's need for improved knowledge about the practice of managing technology.

can be undertaken most effectively by firms that can concentrate on solving their own technology management problems and on contributing their specific results and insights to the body of knowledge in the form of case studies, analytical methodologies, or practice guidelines. A large segment of the set of "potentially researchable/relevant" questions that might be addressed by systematic research can best be tackled by mixed teams. The academic members can contribute their knowledge of the research literature, their theories and models, and their more generic methodologies. The practitioners can provide the practical context and the data as well as their own experience in addressing MoT problems.

Currently, there is a major imbalance. Academics conduct most of the research and publish most of the research results that appear in the literature and at conferences. More active participation by practitioners would help provide the relevance needed for truly useful research.

Currently, the gap in MoT between research and practice is too broad for improved research alone to make a major difference in improving industrial practice and, in turn, the technological competitiveness of U.S industry. It is a goal of the committee and this report to help close that gap (see Figure 1).

Closing this "researchability/relevance" gap will require improved contact and cooperation between researchers and practitioners leading to increased relevance of research ideas and selection of projects, better methodologies for attacking researchable and relevant questions, better training in research methods, increased access to field sites (e.g., industrial companies where the problems exist), and improved technology transfer and field testing mechanisms for the results of research.

DEVELOPING NEW SOURCES OF SUPPORT FOR MoT RESEARCH

A primary need for the MoT field is addressing industry research needs in a rapid and systematic manner. Given the growing and critical need to address MoT issues and the apparent unwillingness or inability of the federal government to face this national concern, the question now is what other funding strategies should be explored.

Traditional funding sources for new programs include foundations, companies, consulting firms, professional societies, universities, state and federal government agencies, and individuals. However, without a coherent, overall architecture for a national MoT funding strategy, the results of any efforts will be fragmented and duplicative and will leave major areas uncovered. There is also the danger of obtaining results that continue to be oriented toward academics speaking to other academics or to solving specific problems for specific companies, rather than to helping improve the general state of knowledge and practice of technology management. Adequate dissemination of results to practitioners is also a problem.

A major issue facing MoT since the NRC's 1987 report is that the boundaries of MoT are still too loosely defined. Many academic interest groups regard it as part of their domain, yet when pressed, they are unable to define it precisely in the context of the business organization. Developing a systematic and coordinated research program on MoT will require that a national strategy be established to encourage development of unified theories of technology management. A national strategy for MoT will determine and publicize *what* research is needed to shape this field, *why and when* it is needed, *for whom* it should be performed, and *who* might perform it. In parallel with this long-term effort, an implementation and funding strategy should be developed to achieve maximum payoff from the limited number of researchers and practitioners that currently are involved in this subject and those who can be attracted to it in the future.

It will be difficult for the diverse set of participants required to agree on such a strategy, or the level of resources required, or how the resources ought to be allocated. The steering group suggests that a strategy be developed gradually. One of the first steps of this strategy should be to identify significant MoT research efforts that share a common set of characteristics and then fund them over the next 3 to 5 years. These characteristics are as follows:

- requiring a collaborative joint effort involving industry (management) and academe;
- incorporating a systems perspective embodying multiple dimensions, breadth and depth, and a holistic view of MoT;
- containing a critical mass, of sufficient size and scale to make a substantial contribution;
- having a broad output by focusing research on important topics of MoT useful to a broad audience *and* aimed at building a set of foundation principles for the field of MoT.

A few years from now it might then be possible—based on the experience of these efforts, the research results, and the application of those results by practicing managers—to reach some consensus on the basic structure and elements of a national strategy regarding MoT. This set of efforts would be a pilot study of the potential impacts of MoT on industrial practice.

University-Industry Research Relationships In MoT

PROBLEMS WITH UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS IN MoT

Improving university-industry research relationships depends not only on understanding specific MoT issues and problems but also on taking into consideration general environmental and organizational issues associated with universities, industry, and their partnerships. Both universities and profit-making corporations have unique histories and, therefore, constraints that they bring to any new venture.

Problems/Issues with Universities

1. *The traditional disciplinary orientation of faculty research constrains an understanding of broad interdisciplinary systems.* Most faculty affiliate with traditional academic departments (e.g., electrical engineering, accounting, finance, economics). The peer group usually evaluates a faculty member based on his/her contribution to the functional field (e.g., economic theory, finance), and most academic journals are highly specialized within this orientation. This culture makes it very difficult to study a total system—one that involves multiple functions interacting in multiple ways.

2. *The language and style of the academic journals*, combined with the large quantity of material being published, make it difficult for managers in industry to pick out useful results.

3. *University structure revolves around traditional functions or disciplines.* The university structure of academic departments reinforces a narrow focus on single-discipline or single-function research. This structure is evidenced by

• a lack of rewards (e.g., recognition or merit pay) for conducting inter- or multidisciplinary research;

• a budgeting and accounting process that creates financial barriers to research that crosses more than one academic department, since such research necessitates revenue sharing between academic departments that are essentially evaluated as independent revenue centers;

• promotions are based primarily on contributions to a single discipline with only rare ones involving contributions across academic departments;

• the application of academic knowledge to practical problems is often frowned upon, occasionally tolerated, and rarely explicitly considered in performance appraisals or judgments of a professor's contributions; and

• the rarity of educational programs that teach a true interdisciplinary systems orientation.

Problems/Issues with Industry

1. *Industry prefers to fund short-term applied research projects that address a recognized immediate need rather than long-term research programs that university faculty tend to undertake.* Moreover, industry considers research to have achieved successful closure when an immediate problem is solved and thus tends to discontinue funding on the research when this is achieved. This behavior conflicts with the academic concept of research, where the focus extends beyond present-day problems toward an understanding of problems in broad contexts. This, of course, requires continued funding, which industry is often disinclined to provide. In addition, much of the research conducted in cooperation with industry in MoT is site specific. The ability to generalize across sites is often of far less interest to the company funding the research than it is to the university researcher.

2. *The functional orientation of industry prevents systems-wide orientation.* Many companies are organized functionally; thus, some funding and measures of research success are based on solving particular functionally oriented problems. For example, a project undertaken to resolve what appears to the company to be a marketing problem, but which actually turns out to be a product development problem, is not likely to be handled as an MoT problem. This issue contributes strongly to the relatively slow acceptance of MoT, since industry struggles to find a single function that can address an issue pervading the entire system.

3. *Company training tends to be functionally focused rather than systems oriented.* Companies tend to create training courses for teaching product-specific or problem-specific skills, without attempting to identify general heuristic skills or skills for broad classes of problems or for understanding the interrelationships between different types of problems and phenomena. There is a strong tendency to train according to the latest and most pressing

specific issue rather than the cross-system implications of a broad *set* of issues. This focus further encourages a narrow orientation toward MoT.

4. *Industry is often slow to use the results of university research on management.* Senior managers do not read the papers produced by academic research; if they did, they probably would not be able to evaluate them. Most management practitioners are extremely wary of the theoretical inputs from universities on the practical aspects of management and are unwilling to expend significant effort to understand the concepts. Even when useful results are gained from the research, the information may not penetrate the higher levels of a company, where many of the major policy decisions needed to put MoT changes into effect must be made.

Problems of University-Industry Partnerships

1. *It is difficult for both sides to be responsive to each other without creating potential conflicts of interest.* University faculty who are very responsive to industry are often negatively evaluated by their academic peers and seen as compromising objective research for financial gain. Similarly, industry people working closely with universities are often told that they are becoming too academic or too "ivory tower" and thus are losing their usefulness to the company. Industry is loathe to provide top-quality people for assignment to collaborative projects given the time horizons and reentry problems. It is not ingrained in the systems of either universities or industry that collaboration can be a positive and ongoing benefit and should be a key part of the mission of each.

2. *Industry has a tendency to lose interest in ongoing research* and can lose interest in the university research projects it funds for a number of reasons. Sometimes the problem being researched becomes less critical or even irrelevant to the company as new issues arise. Sometimes the sponsor of research in a company is moved to another position and his/her replacement is not interested in the research. Reorganization also often changes priorities. These problems are often exacerbated in large projects with a number of corporate sponsors (e.g., consortia).

3. *Working out arrangements for the dissemination of research results can be difficult.* Industry is often perceived as being concerned about the proprietary nature of work done on-site and as putting limitations on what information can be disseminated to the public. Academe is perceived as wanting to spread knowledge "too far." Since university faculty are evaluated based on publications in academic journals (not trade journals), faculty must determine how a particular research study with a company can be made acceptable to an academic journal. Results of broad, practical significance, publication in trade journals, books, or public-speaking tours have proven to be far more beneficial to industry.[13]

IMPROVING UNIVERSITY-INDUSTRY RESEARCH RELATIONSHIPS IN MoT

Many universities have established innovative interdisciplinary programs geared to facilitate MoT research with industry as an active participant. Stanford University, Harvard University, and MIT offer three examples of different interdisciplinary approaches.

The first type is where management is brought into an engineering setting, as demonstrated by the Stanford Institute for Manufacturing and Automation (SIMA). SIMA resides in Stanford's engineering school and provides a model for integrating management research and teaching within an engineering school environment. This program coordinates technology and MoT research activities with 12 companies that invest $85,000 to $100,000 per year and stresses the importance of integrating management and engineering within an engineering environment.[14]

The second type is where MoT issues have been embraced by a business school, such as with the Science and Technology Interest Group at Harvard University's School of Business Administration, which concentrates on the management of science and technology. Harvard's MBA program focuses on science and technology and has four basic objectives: (1) to develop methodologies for researching engineering management, the relationship between technology and technology skills of an organization and competitiveness, and the management of product and process development projects; (2) to integrate technology and management; (3) to develop concepts, principles, and tools for managing the engineering function; and (4) to develop course materials that are appropriate for MBA core, MBA electives, and executive courses.

A third type of university-industry research relationship is a joint venture, such as MIT's Leaders for Manufacturing Program, which involves the business school and the engineering school as partners in the endeavor. Another example of a joint effort is the Manufacturing Vision Group, which involves engineering professors from Stanford, Purdue, and MIT and business school professors from Stanford, Purdue, and Harvard. The Manufacturing Vision Group includes five corporate members (Chaparral Steel, Kodak Corporation, Digital Equipment Corporation, Ford Motor Company, and Hewlett-Packard), which are represented by senior executives as well as engineering managers. There also exists a wide range of university-industry interaction forums that could be grouped under each of the three basic types mentioned above, such as Boston University's Manufacturing Futures Round Table and the Consortium on Competitiveness, which consists of Berkeley, Columbia, Harvard, MIT, and Stanford.

The most common level for industry to participate in university MoT research is through industrial liaison programs in which companies join a program for a set fee. These programs entitle industry participants to certain kinds of interactions with faculty such as individual visits and symposia. For example, there are approximately 300 companies in MIT's industrial liaison program. In order to motivate faculty to pursue collaborative relationships with industry, MIT initiated an incentive program designed to facilitate cooperative programs. The incentive program reserves 10 percent of the earnings from the industrial liaison program, which collects approximately $6 million per year. Points are then allocated to the faculty depending on the nature and frequency of interaction with industry. At the end of the year, the reserve pool of money from the program is divided among the respective budgets of the faculty in proportion to the total points accumulated. The program has proved very effective in motivating faculty members to seek opportunities for collaboration with industry.

While continued new research is very important, significant dissemination of both new and existing MoT research results to industry is crucial. The transfer of ideas and subsequent adoption within separate divisions of a company can be blocked by internal barriers. To move MoT concepts into companies quickly, and to secure significant industrial funding for MoT research, it is necessary to have the support of high-level management. Gaining this support will require clarifying the value of MoT in terms of profitability, time to market, and other factors critical to the firm's performance. High-level executive support will also be contingent upon the presentation of credible strategies for achieving such results. Developing and implementing mechanisms that combine the functions of funding MoT research, opening up companies as sites for that research, and transferring the results and principles developed to industry could prove very worthwhile. In summary, some of the lessons learned by the steering group to help improve university-industry relationships include the need to:

- foster effective university-industry communication at the executive level;
- achieve clear expectations by both parties at the outset of collaborative projects regarding results, patents on prospective products and processes, joint publications, joint working papers, and so forth;
- develop flexible contractual agreements;
- develop a high-level "champion" in a company who is both interested and influential enough to commit funds and promote the collaborative projects; and
- contribute toward the development of a company's skills in technology transfer.

The need for applied and interdisciplinary research has been widely acknowledged by universities, government agencies, and industry, but existing mechanisms have done little more than encourage token efforts while retaining much of the structural and disciplinary constraints inherent in universities, industry, and funding agencies. With this in mind, the following mechanisms are offered for improved university-industry research relationships and dissemination in the area of MoT.

University-Based Mechanisms

1. **Structure**. In U.S. universities, few *true* interdisciplinary applied programs that are independent of single-discipline structures have *both* research and academic (teaching) programs in areas of concern to MoT. Most existing MoT programs are housed within a single discipline and suffer from the problems described previously. In identifying, supporting, and establishing "centers of excellence" in MoT, special attention should be given to finding, encouraging the development of, and supporting true interdisciplinary problem-focused programs that are not tied to single disciplines.

2. **Reward systems**. To encourage the interdisciplinary and applied research needed by industry, universities and accrediting associations must broaden their performance reward systems to encourage faculty participation in and peer acceptance of such activities. Mechanisms for revised performance reward systems might include faculty recognition (and reward) for publication in application-oriented journals, documented industry use of research, participation in workshops for industry, letters of support from industry leaders in MoT, forming close working contacts with industry, and participation in professional programs.

3. **Communication and awareness**. Mechanisms to foster communication between different parts of the university and between universities and industry should be stimulated. Such mechanisms might include rotating university faculty and industry scientists and managers into MoT centers of excellence, establishing postdoctoral fellowships in MoT, and developing sabbatical opportunities for MoT faculty to work in industry.

4. **Graduate programs**. Additional research-based or research-affiliated graduate degree programs in MoT are needed to encourage the long-term growth of MoT resources. Support for fellowships and other educational mechanisms should be sought from government and industry to further the development of MoT graduate education. Courses and course materials (e.g., texts and cases in MoT) should be developed and should reflect current state-of-the-art issues (e.g., adaptive technology, systems architecture).

Industry-Based Mechanisms

1. **Organization structure**. As a result of major publicity and the apparent success of Japanese competitors, quality management and improvement have come to be seen as much more than "inspection." Thus, leading

corporations have put quality representatives on senior staffs. The promotion of more technology managers to senior executive levels would serve to drive home the value of improved MoT. Staffing these new posts would be multidisciplinary general managers (not "traditional" engineers), whose charge would be to facilitate MoT research by breaking down corporate walls between the traditional functions—R&D, manufacturing, engineering, marketing, finance, and personnel—and to help achieve business goals closely related to the speed, cost, and quality with which products come to market. A vice president of technology would continue to direct corporate resources for technology research and development but also MoT, which will enhance the efficiency and productivity of limited research resources.

2. **Reward system**. The industry reward structure does not generally reward people wishing to take cross-functional assignments or to avail themselves of developmental experiences in areas away from their specific expertise. Some corporations have programs for employee sabbaticals in universities; almost universally, reentry issues remain significant and rewards for this learning and risk taking are not attractive. Mechanisms to ameliorate this problem might include formal inclusion of experiences outside of one's specialty in all individual reviews and formal recognition ceremonies for those returning from educational experiences, including participation in research on MoT.

3. **Communication and awareness**. Research in industry is often pursued by individuals who have an affinity for university contacts and who draw on personal experiences to support their value. Rather than rely on this idiosyncratic pursuit of research, industry associations, specific corporations, and functional organizations should make the development of MoT research agendas a normal part of their charters. This would provide direction for research and facilitate the conduct and dissemination of research results. Mechanisms to abet this process might include identifying leading affinity groups and corporations and influencing them to include this topic in their agendas. The *development* and presentation of successful case studies based on MoT research could help to convince companies of the advantage of factoring MoT research into their business plans.

4. **Investment programs**. Research dollars specifically targeted for MoT are needed to help the development of the field. While corporations are subsidizing some MoT ventures, their efforts are not very large or coordinated. Because there is no systematic coordination or monitoring of this activity, it is hard for industry, universities, or the government to see what research is being funded and what areas are being neglected. Competition for MoT grant funds, sponsored by one or more industry consortia, could raise awareness, define research agendas, and increase the momentum and synthesis of MoT research.

5. **Other programs**. Some companies and universities have innovatively smoothed the way for retirement and second-career executives and special-

ists to enter the university environment, where they can disseminate their hands-on experience and fill gaps in the faculty base. These programs, which produce teachers and researchers, provide the distinct opportunity to question and reconsider existing customs and reward systems in U.S. universities. Accrediting associations need to reexamine their criteria and foster increased acceptance of industrial managers into academe. Another promising tactic has been to regard the corporation itself as a *living* laboratory for faculty, research staff, and employees. This tactic could be examined in workshops for those wishing to learn new ways to approach the research experience.

Joint Mechanisms

1. **Guiding principles**. Past experience in university-industry collaboration in MoT and similar fields has shown that there are a number of guiding principles and rules that, if followed, will increase the likelihood of a relationship that is beneficial to both parties. Similarly, there are certain actions that if taken, or not taken, may doom the collaboration to failure. These guiding principles and rules should be collected, codified, tested, and made available to industry and academe.
2. **Electronic network**. Universities today use electronic networks extensively for internal and external communication (to other universities) and to share information, as do companies. Establishing a national MoT bulletin board or electronic conference system that could be accessed from any of the various networks would facilitate rapid dissemination of ideas while also sparking new directions for needed collaboration and research.
3. **Consortia**. Recent programs like MIT's "Leaders For Manufacturing" and "Management in the Nineties" have either broken or leaped over barriers that had been considered insurmountable (in terms of "tradition" and "conflict of interest"). Similar mechanisms could be ideally suited for bridging gaps between departments, between universities and industry, and for creating valuable mechanisms for research in the field of MoT. Consortia offer the opportunity to share the financial and time investment necessary and offer returns from having a wider base from which to extrapolate.

The Government's Role in MoT

MECHANISMS TO FACILITATE MoT RESEARCH AND IMPLEMENTATION

In this report the committee has identified problems with MoT research in universities and with MoT implementation in industry that prevent the normal cycle of research feeding industry and government, which then support research. During the course of its deliberations, the committee discovered many promising—yet often isolated and uncoordinated—approaches to MoT research and implementation.

In universities these include encouraging interdisciplinary programs, broadening performance reward systems, fostering communication between departments of the university and between universities and industry, supporting additional high-quality graduate degree programs in MoT, and developing professional-level continuing education programs. Mechanisms in industry include rewarding people wishing to take cross-functional assignments or developmental experiences, making the development of MoT research agendas a normal part of their organizational objectives, and specifically targeting research funding for MoT. Possible joint university-industry mechanisms include collecting, codifying, and making available guiding MoT practices to industry and academe, establishing a national case library on MoT, and establishing MoT research consortia modeled on recent successful programs.

These vanguard approaches can serve as examples for universities and industries and provide guidance for improved university-industry MoT collaboration. However, in order to achieve a coordinated approach to MoT that can be generally applied to many industries and universities, the committee also came to the conclusion that the role of the federal government was very important.

The government, acting primarily through the National Science Foundation, can do much to help coordinate the appropriate mechanisms needed to facilitate the useful performance of MoT research between industry and universities. In addition, the steering group has identified the National Research Council as an appropriate mechanism to help facilitate the adoption of existing and new MoT techniques and the application of MoT research results.

RECOMMENDATIONS TO FACILITATE THE GOVERNMENT'S ROLE IN MoT

The main task of the steering group is to (1) identify appropriate ways to perform MoT research that benefits industry and (2) find mechanisms that can result in the adoption of new and existing MoT techniques by U.S. industry. This section focuses on the need to expand the roles of the government and its representatives and associates, including industry, in the field of management of technology. The recommendations made here are a call for directed action to aid in the rapid utilization of MoT for competitive advantage.

The steering group looks primarily to the National Science Foundation to provide leadership for supporting the emerging field of MoT and also envisions a further role for the National Research Council. If, however, they choose not to play leadership roles in MoT, the steering group would expect them to be active in helping to find the right venues from which to lead the MoT campaign. To this end, the government is urged to support MoT research in the following ways.

1. Create a central focus for supporting and focusing research on MoT.
Responsibility: *National Science Foundation*
Actions:

• Reestablish support for this field on a substantial, continuing basis by forming a Division for MoT Research within the Directorate of Engineering.

• Convene a blue-ribbon panel to help formulate the mission, objectives, and funding for MoT research. Such a panel should include high-level business executives and technical personnel, leading academic researchers on MoT, and leaders in national technology affairs.

• Support centers of excellence for MoT (see Recommendation 3 for more detail).

• Commission studies to follow-up and monitor the field of MoT (see Recommendation 2 for more detail), to facilitate the implementation of MoT research results, and assist in improvement of MoT research practices.

2. Provide the field of MoT with coordination and guidance.
Responsibility: *National Research Council*

Action: Form a continuing MoT entity. Initial tasks for this entity should include performing studies requested by the National Science Foundation or other government agencies involved in MoT, helping to define goals and objectives for the field, and helping identify strategies for conducting and disseminating MoT research.

Suggested early studies might be to:

• Create a data base of successful MoT practices and techniques for different types of industries and organizations. A manual containing such information could prove to be very useful, since most companies do not now know which MoT methodologies are available.

• Document the "lessons learned" in MoT research into a comprehensive set of examples that describes effective methods for MoT research, particularly collaborative research. An important part of this effort would be to provide examples of how to transfer MoT research results to industry in a timely manner.

3. Provide for strong centers of excellence in the management of technology.

Responsibility: *National Science Foundation*

Action: Support existing and new centers of excellence in the field of MoT over the course of the next few years. The centers should be geographically dispersed as well as broadly focused in terms of topic and industry interest. The centers would, if given the proper financial and advisory support, perform basic and applied research on MoT and related subjects, train both degree candidates and practitioners, and engage heavily in dissemination of the results of MoT research and reports of practice by way of case studies, observed regularities, and descriptive statistics. The centers would conduct seminars and conferences as well as develop new ways to package and encourage use of this new knowledge. Prospective centers should be examined and evaluated according to the following criteria:

• If the National Science Foundation provides seed dollars or matching grants, can the center achieve continuing steady-state industry funding in 3 to 5 years?

• Does the center work in an interdisciplinary manner, integrating what could be considered traditional and nontraditional faculty groupings and research methodologies?

• Has the center gone so far as to design new, nontraditional reward structures?

• Is the center attracting the best and the brightest from academia?

• Is there concrete evidence of close working relationships with government and industry?

- Is the research itself relevant, timely, and contributing to improved knowledge and practice?
- Are center members (faculty, graduate students, and other researchers) rewarded for publishing in *both* scholarly and practitioner-oriented journals, magazines, and other management-oriented publications?
- Is the research application oriented, with a bias toward successful implementation?
- Is the urgency of MoT issues reflected in research plans aimed at achieving rapid results and quick analysis within careful academic guidelines?
- Is the global nature of MoT issues considered in research plans?

Notes

[1] National Science Board, *Science and Engineering Indicators—1989*, Washington, D.C., U.S. Government Printing Office, 1989.

[2] Task Force on Management of Technology, 1987, *Management of Technology: The Hidden Competitive Advantage*, Washington, D.C., National Academy Press.

[3] For example, in the pharmaceutical industry, companies have tended historically to spend 15 percent of sales on R&D.

[4] K. Clark and T. Fujimoto compared the lead times for a set of major body panel dies as they progressed from preliminary drawing release for tooling order, to final drawing release, to delivery and completion of tryout. Europe averaged 27.6 months, Japan averaged 13.8 months, and the United States averaged 24.8 months. See "Overlapping Problem Solving in Product Development," *Managing International Manufacturing*, K. Ferdows, ed., Amsterdam, North Holland Press, 1989, pp. 127-152.

[5] According to a 1990 Department of Commerce report, the United States lags Japan in product introduction in 5 of 12 advanced technologies and the trend is worsening in 9 of the 12. The United States lags Europe in 2 of the same 12 technologies, with the trend worsening in 3. See Table 3. "Relative Standing in Emerging Technologies: U.S. versus Japan and EC," *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Department of Commerce, Washington, D.C., Spring 1990, p. 13; and "Summary of Foreign Technological Capabilities," *Critical Technologies Plan for the Armed Services and the United States Congress*, Department of Defense, Washington, D.C., March 15, 1990, Table 5, p. 11.

[6] One example of a research center and chair in manufacturing is SIMA (Stanford Institute for Manufacturing Automation), which was established and funded by industry for research in MoT. The Stanford Business School

also has a chair (established by Kleiner, Perkins, Caufield, and Byers) that focuses primarily on technology and its management.

[7] Examples include those at the universities of Alabama in Huntsville, Southern California, Minnesota, and Toronto, the New Jersey Institute of Technology, and Fairleigh Dickinson University.

[8] For example, the new Center for Information and Telecommunication Technology (CITT) at Northwestern University is strongly supported by industry.

[9] National Science Board, *op. cit.*

[10] There currently are over a dozen journals that publish articles on MoT. Some, such as *Transactions on Engineering Management of IEEE*, *R&D Management*, *Research and Technology Management*, *Product Innovation and Management*, *International Journal of Technology Management*, and the *Journal of Engineering and Technology Management*, cover a broad spectrum of topics. Some are oriented to both practitioners and researchers. Some concentrate on one or the other type of audience, with small readership lists. It was noted that these publications (and others like them) are accorded low status by some academics because of their "problem focus" relative to the status of publications in more theoretical journals. This differential in status effectively steers some young researchers away from considering MoT as their major field of research.

[11] See, for example, *Manufacturing Strategy: The Research Agenda for the Next Decade*, J. E. Ettlie, M. C. Burnstein, and A. Fiegenbaum, eds., Joint Industry Conference on Manufacturing Strategy, Ann Arbor, Michigan, January 8-9, 1990, Boston, MA, Kluwer Academic Publishers; *Managing the Design/Manufacturing Process*, by J. E. Ettlie and H. W. Stoll, New York, McGraw-Hill, 1991; and *Technology Strategy: A Guide to the Literature*, by P. S. Adler, Greenwich, CN, JAI Press, Inc.1989.

[12] See "Is Research in the Ivory Tower 'Fuzzy, Irrelevant, Pretentious'?" *Business Week*, Oct. 29, 1990, pp. 62-63.

[13] When research results on management principles have been effectively translated into "managerial speak," they often appear to have a major impact on decision making (e.g., T. J. Peters and R. H. Waterman, *In Search of Excellence*, and M. Porter, *Competitive Strategy*).

[14] Recently the Stanford Graduate School of Business has begun to play a more active role in SIMA, and as of Oct. 1990 SIMA's (acting) directorship is shared across the two schools.

Appendix A
Comments on a Possible Taxonomy for the Field of MoT

Research on MoT, after a leveling off in the 1970s, has begun to grow again as a focus of people from many disciplines and applied fields, such as various branches of behavioral science, economics, political science, business, and management as well as engineering management, technology management, research management, production and operations management, information and telecommunications technology, and policy. As a result, there is no clear agreement on the boundaries, paradigms, or "approved methodologies" in the field. This situation is not unfamiliar in many of the growing number of hybrid or cross-disciplinary fields. The search for a clean, inclusive, and exclusive definition is not likely to prove successful and is likely to waste the time and energy of groups such as the committee that issued this report. A wise course on this issue is to view the field, for the moment, as including many problem areas, disciplines, approaches, styles of research, and focal phenomena.

The definition or "boundary" questions keep arising: "What *is* MoT? What are its inclusive boundaries? What is outside the field?" The field is too young *and too amorphous* to attempt a rigorous definition that will provide firm inclusion and exclusion criteria, let alone establish a stringent taxonomy that provides a structure for the field in terms of exhaustive categories that are mutually exclusive. For the present, we have to allow wide latitude for inclusion of activities by researchers and practitioners, so that eventually we can sort out the "real" issues and the relevant research topics that are put forth under the general MoT rubric or under similar general descriptions, such as "research on research," "management of the R&D/innovation process," and others in terms widely used in the literature. A useful taxonomy for the future development of the field will include a combination of the practical aspects of actually managing technology and the research aspects of studying it as a phenomenon. Such a taxonomy will have several dimensions, such as:

- **Scope of the field**. The committee adopts the view that a wide spectrum of activities are included in MoT, best characterized by the R&D/ innovation spectrum itself (e.g., research, development, engineering, manufacturing, commercialization—all related to new and improved products and processes). Also included are important supporting activities such as manufacturing engineering, market research for new products, relevant financial analysis, venture management, and technology planning and strategy.

- **Kinds of issues/problems**. Many types of issues and problems cut across the functions mentioned under "scope," such as evaluation, project management, interface relations, design review, and monitoring of progress.
- **Research or problem-solving approach**. Research-related activities and issues can be approached by academic researchers or managers in a variety of ways: incrementally, personal experience and/or intuition, experimentation (laboratory or field), survey of current practice, proposition development and test, case studies, and real-time studies.

There may be additional dimensions on which a useful taxonomy can be based. However, these provide a reasonable starting point. Eventually, a taxonomy (or more than one) may be useful to continue structuring the field as it develops in both practice and research. For the moment, we may have to be content with the current alliance of existing sets of issues, problems, and research topics reflecting the research, literature, and continuing direction in *which business and technology is heading*.

Appendix B
Presentations on University-Industry Activities

Presentations on university-industry collaboration, particularly in the field of management of technology, were made on November 10, 1989, to the Steering Group for Research on Management of Engineering and Technology by the following individuals:

Thomas J. Allen, Alfred P. Sloan School of Management, Massachusetts Institute of Technology

John F. Cassidy, Corporate Director of Technology Management, United Technologies Corporate Office

Alok K. Chakrabarti, Dean, School of Industrial Management, New Jersey Institute of Technology

Robert W. DeSio, Vice President for Development and Long-Range Planning, National Technological University

John E. Ettlie, Director, Office of Manufacturing Research, Graduate School of Business Administration, University of Michigan

Dorothy Leonard-Barton, Associate Professor, Harvard Graduate School of Business, Harvard University

Joan Mokray, Technical Resource Development Manager, Digital Equipment Corporation

Pete J. Rafferty, President, Technovation

William E. Souder, Professor, Industrial Engineering, Systems Management Engineering, and Operational Research, University of Pittsburgh (now at the University of Alabama in Huntsville)

Steven C. Wheelwright, Professor of Business Administration, Graduate School of Business Administration, Harvard School of Business, Harvard University

A case study on university-industry collaboration by Northwestern University's Program of Research on the Management of Research and Development (POMRAD) and the Center for Information and Telecommunication Technology (CITT) was presented by Albert H. Rubenstein, Director of POMRAD and CITT. In addition, a case study by the Department of Chemical Engineering at Carnegie Mellon University was presented by Arthur W. Westerberg, Swearingen Professor of Chemical Engineering.