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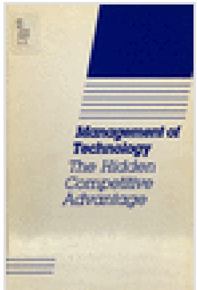

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MANAGEMENT OF TECHNOLOGY: THE HIDDEN COMPETITIVE ADVANTAGE

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Preface

The relative decline in the international competitiveness of U.S. industries has become a major focus of national debate. The symptoms are increasingly clear—record trade deficits, poor productivity growth, loss of technical leadership in a growing number of high-technology industries—but cures are difficult and complex. Many proposed solutions focus on economics and trade policy; others emphasize basic technology and education. One potential solution that is often overlooked lies in improving how Americans manage technology development and implementation.

Under the aegis of the Cross-Disciplinary Engineering Research Committee and the Manufacturing Studies Board, a steering group planned and, in May 1986, conducted a workshop to examine the state of research, education, and practice in the management of technology. The workshop was attended by representatives of key universities and industrial organizations involved in the management of technology.

After the workshop a Task Force on Management of Technology, also under the aegis of the Cross-Disciplinary Engineering Research Committee and the Manufacturing Studies Board, was appointed to distill and expand the results of that workshop. The task force held one meeting in July 1986. This is the report of the task force.

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Executive Summary

To an ever-increasing extent, advanced technologies are a pervasive and crucial factor in the success of private corporations, the effectiveness of many government operations, and the well-being of national economies. Successful development and implementation of advanced technologies requires careful attention not only to scientific and engineering advances and resulting capabilities, but also to people, raw materials, financial feasibility, and the competitive environment. Appropriate consideration of each of these factors requires conscious choices and actions, and achieving an appropriate balance is an increasingly difficult problem for modern managers. It is a problem of technology management.

There is empirical evidence that U.S. managers in industry as well as government could improve their technology management techniques. The difficult choices involved in developing and implementing new technologies are recognized, but the right choice is rarely well defined and progress is often subject to trial and error. One of the few consistent themes in technology management strategies seems to be that it is better to devote more resources to research and development (R&D) than less. In too many cases, however, guidelines for allocating those resources among projects are vague, schedules are necessarily imprecise, and results can be unpredictable.

Furthermore, limiting the concept of technology management to R&D is inadequate. Once a new product or process technology

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is developed, successful integration of the new capabilities into current operations can be elusive, particularly when major changes are necessary in upstream and downstream operations, labor utilization, and financial and marketing strategies. Managers have always accepted these difficulties as inevitable and unavoidable, but they are increasingly unacceptable in an era of rapidly changing technology. A better understanding of the causes of these inefficiencies and better tools for improving the technology development and implementation process would allow U.S. managers to use new technologies more effectively.

In an effort to assess the current state and future direction of technology management in U.S. industry and academe, the Cross-Disciplinary Engineering Research Committee and the Manufacturing Studies Board organized a steering group to plan and conduct in May 1986 a workshop of experts in the field. The workshop was attended by representatives of key universities and industrial organizations, who discussed the state of research, education, and practice in the management of technology (MOT). After the workshop, a task force was organized to draft the results and prepare recommendations.

The workshop participants agreed that academic work in the field of MOT has the potential to address many of the current shortcomings in technology management. Progress requires an improved understanding of the innovation process, the changing nature and speed of technology development, and the role of technology and MOT in determining competitiveness. Such an understanding must be based on the development of theories supported by experiential evidence and facts, a process that can only occur if the field of MOT receives more scholarly attention.

MOT links engineering, science, and management disciplines to address the planning, development, and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organization. Although MOT has existed as a limited field for at least 25 years, it has not attained the status of a recognized discipline. Rather, it should be viewed as an emerging interdisciplinary field.

Education and research efforts in MOT are fragmented and uncoordinated. The field receives little research funding, the number of faculty involved is small, and there are relatively few

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well-structured educational programs—particularly with a business/engineering orientation. So far, the most successful educational delivery mechanisms appear to be short courses and mid-career master's programs offered to industrial managers.

Although corporate emphasis on MOT as a distinct area in management development programs is uncommon, some large technology-based corporations operate in-house training programs in areas such as engineering project management and management of innovation. They also send managers to university short courses and commercial seminars on aspects of the subject. A few corporations are beginning to pursue more comprehensive programs in MOT, either in-house or in collaboration with local universities, but are finding a shortage of faculty qualified to design and teach effective courses. Most corporate management development programs, however, continue to focus on more traditional management training and either ignore MOT issues or subsume them under other topics and treat them peripherally.

Industrial leaders have been skeptical of the applicability of academic research and education in MOT to the needs of their organizations. Many believe that their companies are already doing a reasonably good job of managing technology; they doubt there is any real difference between MOT and management in general.

Many academics are also skeptical about MOT. They believe that research and education in traditional engineering and business disciplines remains the most effective approach to broaden the general technology knowledge base. Consequently, there is some institutional and personal resistance to the idea of collaboration among universities or between business and engineering schools—although a few schools do have successful joint programs or courses in MOT.

Despite this skepticism, most faculty researchers in the field of MOT assert that their work can have great benefits for industry, particularly if their programs could overcome a number of current constraints. Funds for the research needed to develop the knowledge base are limited, there are few faculty involved, and industry is hesitant to hire MOT graduates. Although there is potential for more industrial support, faculty are reluctant to be driven too closely by industry's needs—especially its immediate and specific needs. Instead of filling industry's relatively short-term training needs, MOT faculty would prefer long-term support for research to

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build their knowledge base and to improve educational programs in MOT.

Based on the results of the workshop and their experiences in industry and academe, the task force concluded that rapid progress in strengthening the field of MOT through cross-disciplinary research and subsequent curriculum development will require support from government, academe, and industry. Although the field is not formally codified, there is an extensive body of knowledge in MOT and related areas. The recommended approach is to build on existing knowledge and capabilities while giving more emphasis to MOT issues in the training of both engineers and managers. That approach should be a continuous process in which progress in research adds content to the curriculum and drives the development of needed management tools and insights, which in turn are tested by industry. The results of experimentation would then be disseminated through publication, education programs, and consultation.

The task force recommends a three-part process for evolving the MOT body of knowledge. In Phase I, the National Science Foundation (NSF) would begin building awareness of this issue's importance among the nation's educators, researchers, and industrial managers. In Phase II, NSF, the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) would support MOT research through grants to individuals and small groups, postdoctoral fellowships, and conferences. Industry should act as a partner with academe in this research, providing support and helping to identify its needs. The university community should contribute through greater acceptance of cross-disciplinary and problem-oriented research, the participation of tenured faculty, and by other means.

Phase III would be contingent on the demonstration in Phase II that MOT research and education is yielding implementable results beneficial to U.S. industry. If so, the NSF and DOD should consider establishing one or more long-term funded cross-disciplinary university research centers in MOT. Industry should then begin providing manpower, access to its MOT methodologies, and more substantial funding for academic research and education in MOT. Finally, other government agencies and private foundations should initiate their own support programs for work in MOT.

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1
Roots of the Problem

The need to manage technology effectively is not a new phenomenon. The ability to develop and use new technologies has been a hallmark of the industrialization of the U.S. economy. However, there are a number of features of the current, intensely competitive global environment that demand renewed emphasis on effective technology management and a reevaluation of traditional techniques. For example:

- The pace at which new product and process technology is generated throughout the world has grown exponentially, creating new markets and rapidly changing sources of competitiveness. U.S. companies must stay abreast of and, when possible, lead these changes through both internal innovation and effective assimilation of external developments.
- New developments in science and engineering and increasingly sophisticated consumers have provided the technological capabilities and market incentives to shorten product life cycles. To cite one familiar example, barely 3 years after their introduction, compact disc players have made significant inroads on the audio entertainment market long shared by cassette tapes and phonograph records. Soon, however, compact disc recorders will be introduced, making the play-only equipment obsolete. These machines, in turn, will face strong competition from new digital audio tape technology, which has already been developed but has not yet been released in consumer products. As such developments spread to a growing number of markets, continuing traditional emphasis

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on standardized products and economies of scale will be a disadvantage. Successful companies will need to learn how to respond rapidly and flexibly to changing market demands and how to apply new technologies to those demands quickly, even when their own products are made obsolete.

- Related to this reduction in product life cycles is the need to cut product development times. International competitors are successfully reducing the lead time from initial product conception to high-volume manufacture by conducting product/process design and engineering functions in parallel as much as possible. Japanese automobile makers, for example, have used this approach to lower new product development times to 3–4 years versus 6 years for U.S. companies. New technologies, particularly computer-aided design and manufacturing, will help manufacturers achieve this concurrence of functions, but the key (and the source of the Japanese success) is effective management.
- Given the nature of international competition and the many sources of new technologies, companies must develop technology strategies for maximizing competitiveness. Determining whether the company will be an innovator—that is, a market leader in new technologies—a rapid imitator, or a licensor of other companies' developments will be an increasingly crucial decision for managers, and there are few clear guidelines on which to base such determinations.
- With rapid changes in product lines and production technologies, the traditional bases for corporate decisions about technology are less and less effective. Short product life cycles, rapid innovations in process technologies, and constant competitive pressures will create different cost structures, investment justifications, and strategic priorities. In many industries, sufficient amortization of dedicated production equipment will become impossible, leading companies to adopt flexible equipment that can adapt to changing production needs. Facilities will need to be managed as integrated systems, which means that allocating costs and depreciating equipment in traditional ways will be increasingly arbitrary. As technology changes, the tools of management will also need to change, but the process of determining what those new tools should be is in its infancy.

These issues are not confined to the manufacturing sector. For instance, the entire distribution chain is confronted with the

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phenomenon of short product lives. How to juggle orders of new and not-so-new products, how to allocate marketing efforts, and how to respond to increasingly heterogeneous market niches are examples of the growing problems in a number of relevant service industries. Even in the public sphere, the increasing technological complexity of activities such as space exploration and basic research in genetics demands fresh attention to the management of the technology development and implementation process.

These kinds of considerations clearly demonstrate the inadequacy of many current approaches to managing technological resources. Often, investments in new technology, renewed emphasis on R&D, or efforts to match the new products of competitors do not fulfill expectations, but the reasons are not readily apparent. A growing number of managers are beginning to recognize that the problem may be due to an inability to measure results effectively as well as to shortcomings in traditional management approaches. Unfortunately, in most cases there are no viable alternatives. There are few principles to follow, few examples to emulate, and developing new approaches usually involves an expensive process of trial and error that few companies can afford.

To overcome these shortcomings in traditional management practices and to improve MOT, new strategies and mechanisms will need to be developed. Not only will managers need an acute awareness of the importance of technology in shaping the economic future of their firms, but also they will need the knowledge and the courage to implement the necessary changes in the structure and behavior of their organizations. The required changes will be pervasive and the transition from traditional attitudes and mechanisms will be difficult. The quicker and smoother this transition is, the better will be the long-term outlook for U.S. companies and the U.S. economy.

Effective work in the field of MOT will be an important resource in efforts to understand the effects of technology on strategies, skill requirements, and organizational structures (see Figure 1). This report outlines an approach by which an accelerated development of research and education in MOT can be achieved. It will also suggest a broad research agenda based on the most pressing needs of U.S. industry. First, however, it is important to define the field of MOT.

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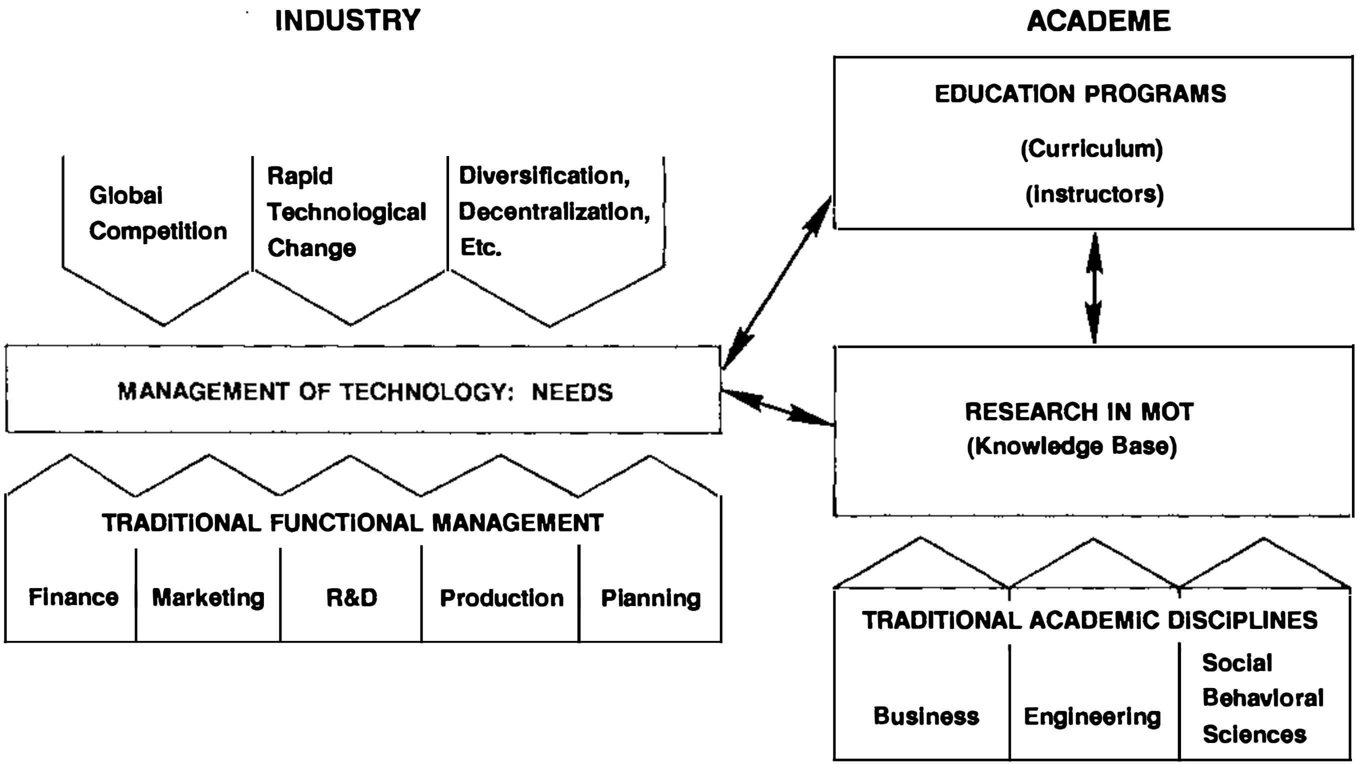

FIGURE 1 Drivers of MOT.

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2
What is "Management of Technology"?

DEFINITION

Management of technology is an industrial activity and an emerging field of education and research that is not generally well recognized or even consistently defined. It concerns the process of managing technology development, implementation, and diffusion in industrial or governmental organizations. In addition to managing the innovation process through R&D, it includes managing the introduction and use of technology in products, in manufacturing processes, and in other corporate functions. The following definition encompasses these different aspects of MOT:

> Management of technology links engineering, science, and management disciplines to plan, develop, and implement *technological* capabilities to shape and accomplish the strategic and operational objectives of an organization.

Key elements of MOT in industrial practice are (1) the identification and evaluation of technological options; (2) management of R&D itself, including determining project feasibility; (3) integration of technology into the company's overall operations; (4) implementation of new technologies in a product and/or process; and (5) obsolescence and replacement.

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SCOPE

Academically, aspects of the field of MOT are being addressed in different but overlapping ways through research and education in a few schools of engineering and of business (and to some extent within the social and behavioral sciences). These approaches have many different names, depending on the orientation of the individual program: technology management, management of innovation, management of R&D, engineering management, and manufacturing systems management. There are a great many different specific elements of research and education, ranging from the more theoretical (e.g., the mathematics of R&D portfolio optimization) to the highly operational (e.g., production scheduling).

Figure 2 illustrates the perception of the task force that MOT is a distinct field evolving from the interdisciplinary bridging and linkage of engineering/science and business management. Listed next to the graphic are those MOT-related issues and responsibilities that are perceived to be specifically in the province of either engineering/science or management.

Figure 3 lists in more detail the issues and responsibilities that are specific to MOT and that drive current efforts in research and education within it. Note that they can be grouped into four categories of technology-related issues:

1. strategic (or long-term) issues;
2. interfunctional policy issues;
3. current research, development, engineering, and operations (RDE&O) issues; and
4. support services/issues in technology management.

STATUS OF THE FIELD

The following summary of the status of the field of MOT in academe and industry is derived from a brief survey and a workshop on MOT held in May 1986 (see Preface) involving most of the universities and a representative sampling of companies active in this field.

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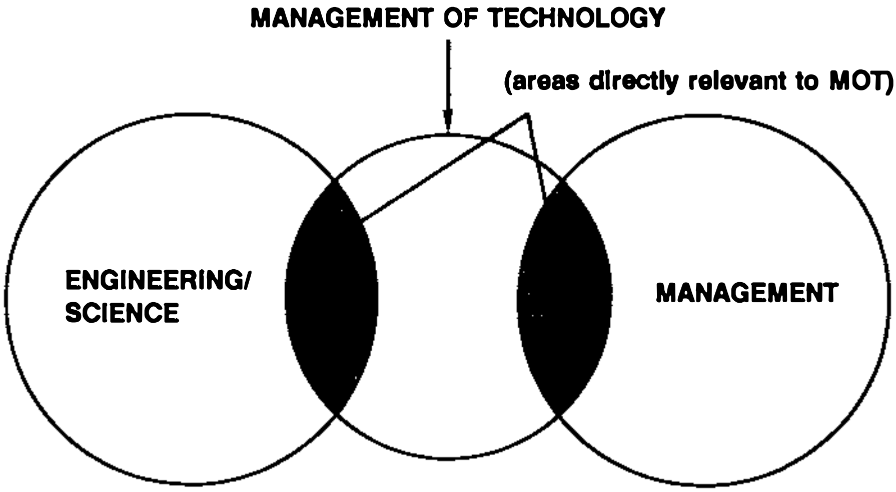

- Discipline-based knowledge
- Engineering Systems
- Computing Applications
- Manufacturing Technology
- Design (DFA, etc.)[1]
- Risk Analysis
- Control Theory
- CAD/CAM[2]
- Quality Assurance/Statistics
- Operations Research
- MIS/DSS[3]
- Reverse Engineering
- Awareness of Available Technologies
- Strategic/Long-term Issues Relating to Technology
- Interfunctional Issues Relating to Technology

- RDE&M[4] Current Operations Issues
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- Business Policy/Strategy
- Control/Accounting
- Organizational Behavior
- Human Resource Management
- Production and Operations Management
- R&D Management
- Managerial Decision Theory/ Statistics/Operations Research
- Macroeconomics/International Trade
- Microeconomics
- MIS/DSS[3]

[1]DFA: Design for Automation or Assembly.
[2]CAD/CAM: Computer-Aided Design and Manufacturing.
[3]MIS/DSS: Management Information Systems and Decision Support Systems.
[4]RDE&M: Research, Development, Engineering and Manufacturing.

FIGURE 2 MOT Links, Issues, and Responsibilities.

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Academe

Education Programs

Although facets of MOT have existed as a focus of research and teaching in a few universities for at least 25 years, it is not a recognized discipline. Instead, it is best characterized as an interdisciplinary field of study, with a small but active following in industry and academe. The degree of activity in MOT varies greatly across schools and universities. The further development of the field will require considerably greater activity at several major universities. Table 1 details the extent of educational involvement among 13 of the more active universities.

Degree programs and course offerings in MOT are found at all levels, from undergraduate through doctorate programs, although most stop at the master's level. (MIT and Northwestern have awarded doctoral degrees explicitly in this field.) A few schools offer a "concentration," or major field, within the MBA degree or within a Master of Manufacturing (or Industrial) Engineering program. Joint engineering/business courses and degree programs at the master's level are few in number and in general many more business school than engineering school courses relate to MOT. For undergraduates, many of the courses come under the rubric of Science, Technology, and Society (or the equivalent); undergraduate *majors* in this area do not exist.

A sizable number of continuing education programs are offered by colleges, professional societies, and other institutions directed at working engineers and scientists. Some of these programs lead to a master's degree in Management of Technology or Engineering Management, as an alternative to the mid-career MBA, for example. However, it should be emphasized that, although there are areas of similarity, engineering management is not the same as technology management.

A primary consideration in evaluating the adequacy of current educational programs in MOT is the desirability of graduating experts in MOT. Many industrial managers and academics argue that graduating MOT experts is not an effective use of MOT resources. The range of functions and decisions affected by technological developments is such that MOT specialists would be of limited value in the industrial world. They argue that the real and urgent need is to instill in all engineers and managers a better

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1. <u>Strategic/Long-Term Issues Relating to Technology</u>
   - Entrepreneurship (managing innovation)
   - Research, development, engineering, and operations (RDE&O) strategic planning
   - National and international policies (regulatory, trade, environmental)
   - Forecasting/assessment
   - Technological alliances (sourcing/leveraging)
   - Marketing/technical linkage (product conceptualization, design, and support)
   - Managing for technological change (obsolescence/discontinuity)
   - Acquisition and joint venture negotiations

2. <u>Interfunctional Policy Issues Relating to Technology</u>
   - Entrepreneurship (internal ventures)
   - Technology transfer
   - Sociotechnical systems design (man/machine interface)
   - Organizational interfaces
     a. Marketing/R&D
     b. Manufacturing/R&D
     c. Administration/R&D

3. <u>Current RDE&O Issues</u>
   - Project management
     a. Internal/multiorganizational
     b. Small/big
     c. Simple/complex
   - Managing technical professionals/organizations
   - Managing quality/productivity
   - Productivity through technology
   - Crisis management
   - R&D management--systems/process
   - New product development
   - Vendor management
   - Training of R&D/technology managers

4. <u>Technology Support Services and Issues</u>
   - Management information system development and utilization
   - Human resources management, labor-management negotiations
   - Law (licensing/intellectual property/joint venture)
   - Risk/reward analysis
   - Technological economics
   - Ethics and social impacts
   - Expert systems in technology management

FIGURE 3 MOT ISSUES. Issues and responsibilities specific to MOT fall in the area linking management and engineering/science.

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TABLE 1 Current Management of Technology (MOT) Education Programs (Selected Universities)

University/ School	Category A	B	C	D
Carnegie-Mellon				
Business			X	
Engineering			X	
Columbia				
Business			X	
Engineering				X
Harvard				
Engineering				X
Lehigh				
Business		X		
Engineering		X		
MIT				
Business	X[a]			
Engineering	X[a]			
Michigan				
Business			X	
Engineering			X	
Northwestern				
Business			X	
Engineering	X			
Pennsylvania State				
Business		X		
Engineering		X		
U. Pennsylvania				
Business	X[a]			
Engineering	X[a]			
Purdue				
Business			X	
Engineering			X	
RPI				
Business	X[a]			
Engineering	X[a]			
Stanford				
Business			X[a]	
Engineering	X[a]			
Yale				
Business			X[a]	
Engineering			X[a]	

NOTE: MIT = Massachusetts Institute of Technology; RPI = Rensselaer Polytechnic Institute. Category A: Undergraduate and/or graduate degree major option(s) offered in MOT or equivalent. Category B: Numerous courses offered in MOT and related subjects, but not a degree option. Category C: A few (1-4) courses offered in MOT or equivalent, but no particular focus on MOT as a distinct field of study. Category D: No courses currently being offered in MOT.

[a] Separate and joint programs

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understanding of the many aspects of MOT by including MOT coursework in standard engineering and management curricula. Such an approach would be more successful in changing both academic and industrial cultures to reflect the crucial importance of technology and technology management in the success of modern organizations.

Research

Research efforts in MOT at U.S. universities are presently limited, fragmented, and uncoordinated across the various subfields. The literature is highly diverse, lacking both unity of language and a consensus on the research approaches and paradigms to be pursued. The body of knowledge needed to underpin a comprehensive theory either does not yet exist or a consensus has not been reached. To date, many partial theories and/or models have been put forward for testing, and useful results have been obtained, but the focus of the research is diffused.

The field as a whole receives very little research funding. The NSF, under its Industry-University Cooperative Research Centers Program, supports an MOT research center in innovation management at Lehigh University; NASA and the DOD provide some funding to individuals; and there are numerous small industry-sponsored projects. The different approaches taken by schools of engineering and business mean that there are widely differing technical aspects of the field, including modeling, mathematics, and analytic techniques. Another constraint is that academic researchers find it difficult to gain access to industrial and government projects for MOT research.

One reason why the field has had difficulty taking hold in universities is that, compared to other areas of university research, MOT is strongly problem-driven. Consequently, it is viewed somewhat skeptically by discipline-oriented research faculty. Being problem-driven, it is cross-disciplinary in nature, and so suffers from the same problems of acceptance that all such fields experience. Business, science, and engineering faculties tend to see it as lacking rigor. As has been the case in the past with other emerging fields (e.g., manufacturing), it will require the development of a critical mass of faculty along with continuity of support to overcome these problems.

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The universities currently active in MOT have several characteristics:

- strong schools of science and engineering;
- strong schools of general management, or small schools of management with a focus on MOT;
- a culture that supports interdisciplinary research and education;
- a research orientation; and
- active ties with industry.

Industry

Practice

Operationally, most industrial firms take a pragmatic approach toward managing technology; they do not view it as a distinct art or as being any different from overall corporate management. Several large companies have explicit "technology strategies" or management policies by which they attempt to systematize technology development and integrate it into the business strategies of the firm. Others, however, end up focusing primarily on one aspect of MOT, such as technology transfer or integration of functions. Small, highly focused, technology-driven companies seem to have the best operational handle on many aspects of technology management. Because all industries will be more technology-driven in the future, it will be increasingly vital for every company to have some form of technology strategy.

Corporate RDE&O managers surveyed and represented in the workshop generally believe that their companies manage technology well, and they all agree that doing so is an increasingly important key to their business success. Most will admit that they have some problems, but they tend to have trouble articulating the exact nature of those problems. The most commonly identified difficulties fall into the areas of: justifying investments in new technology, overemphasis on product technology versus process technology, and the timing of changes in product/process technology. Those managers who are most confident of their company's ability to manage technology effectively are in industries not yet facing strong foreign competition (e.g., aerospace, chemical processing). Managers from industries in competitive difficulty (e.g.,

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automobiles, electronics) are more aware of deficiencies in how they manage technology, at least in specific areas such as product development times.

There is general agreement among managers that the basic goals of improved MOT should be to increase the effectiveness of R&D and to facilitate the transfer of R&D findings into competitive products, processes, and systems.

In-House Education

To strengthen the skills of their technology managers, companies rely primarily on selection, experience, and a smattering of "executive education" programs offered by some universities to mid-career technical managers. Most large companies offer their managers a few MOT-related courses on topics such as project management. However, the present and future needs for this kind of education are much greater than the existing programs—academic or corporate—can fulfill. At present, IBM is the only U.S. corporation known to have an internal educational program specifically in MOT and it is having difficulty recruiting expert faculty for the program. General Motors is currently considering whether to initiate such a program. Small and medium-sized companies are at a distinct disadvantage because they often cannot afford or are unable to offer this type of education, or any other professional-level education, in-house.

Offering or obtaining increased education in MOT should not be the only concern of corporations struggling to improve their technology management skills. There must also be the assurance that the courses provide the kinds of skills or analytical approaches that are appropriate for the organization. Perhaps more important, the corporation must have the kind of culture that allows, even encourages, managers to implement these skills. This latter factor may be the most crucial shortcoming in U.S. MOT efforts.

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3
Defining a Problem-Driven Research Agenda

RATIONALE

The scope of present (and past) research in MOT was outlined in Figure 3. The items in those lists have received differing amounts of research attention, based on a combination of factors such as shifting industry directions, academic fashions, and changes in the technological and economic environments. At all times, shortages of funding and research talent have constrained and distorted the research agenda nationally across the field of MOT.

There is little point in attempting to assess the state of knowledge within each topical area and then to compare them all against each other and against the nation's industrial needs. Such a procedure would be at best subjective and would also tend to restrict the field's growth into new areas that may not yet be apparent. There would be a danger of defining too narrowly the boundaries of both the field and the necessary research. As described earlier, the knowledge base in MOT is fragmented and undeveloped. What is needed at this time is not overdefinition and restriction, but freedom.

Nevertheless, the field of MOT deserves more attention precisely because of the urgent need for the concepts, techniques, and managerial insights that it offers. Therefore, it is important to provide some organizing principles that can help in rationalizing the near-term response to the problem of technological competitiveness.

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Eight major technology-related needs or issues facing U.S. industries can be identified, all of which will be increasingly important to their future competitiveness. All eight are areas in which the ability of researchers to provide authoritative help is quite limited at present and in which better solutions based on research could have considerable impact. Although the research agenda in MOT must be largely problem-driven, it should be emphasized that the eventual codification of knowledge for use in education will depend on performing a certain amount of basic research that could generate the unifying models, theories, and curricula that the field now lacks.

Traditional academic disciplines and fields that are or would be primary contributors to the MOT response in each area are listed after a brief description of the needs.

PRIMARY INDUSTRY NEEDS IN MOT

1. *How to integrate technology into the overall strategic objectives of the firm.* This area includes the allocation of corporate resources to and within RDE&O, planning for technology development or acquisition programs, and other near- and long-term strategy questions. [Strategy, Operations Research, Organizational Behavior, Finance]

2. *How to get into and out of technologies faster and more efficiently.* This area includes the selection of new technologies, their prioritization, and the timing of their introduction and discontinuation, as well as assessing possible alternatives to new technology investments. [Strategy, Organizational Behavior, Marketing, Science, Engineering]

3. *How to assess/evaluate technology more effectively.* This area includes evaluating the current and future competitiveness of a company's technology, the relative risk of in-house development versus acquisition, the pace of future changes in technology and potential markets, and potential return on investment in financial as well as strategic terms. [Engineering, Science, Operations Research, Organizational Behavior, Risk Analysis, Marketing, Accounting]

4. *How best to accomplish technology transfer.* At the corporate level, two basic areas of technology transfer need attention: (a) transferring R&D results efficiently into design and manufacturing and (b) assimilating externally developed technology and

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research results into the company's internal RDE&O activities. [Engineering, Science, Manufacturing, Organizational Behavior, Strategy, Political Science]

5. *How to reduce new product development time.* How can the links among design, engineering, and manufacturing be improved? Greater coordination of these functions and parallel efforts could greatly reduce the lag between product conception and market delivery. [Strategy, Organizational Behavior, Engineering, Science]

6. *How to manage large, complex, and interdisciplinary or interorganizational projects/systems.* This is the traditional area of "project management" but with new dimensions of complexity wrought by many of today's product/process technologies and business practices (diversification, joint ventures, etc.). The key problem is recognizing the interrelationship of functions in the total system and managing the organization as a system to meet budget, schedule, and performance goals. [Organizational Behavior, Operations Research, Political Science, Strategy]

7. *How to manage the organization's internal use of technology.* This area includes the smooth introduction and management of operations technologies (e.g., design/manufacturing automation), and operations-support technologies such as management information systems, automated banking systems, etc. [Industrial Engineering, Organizational Behavior, Human Resources Management]

8. *How to leverage the effectiveness of technical professionals.* This area deals with the unique managerial needs of the technical professional—division of technical work, functional organization and staffing, professional development, and so on. It includes topics such as motivation, measurement, training, supervision, obsolescence, etc. This area has received the largest amount of research attention and industry interest, yet the many separate topics studied are not well integrated. [Organizational Behavior, Human Resources Management, Engineering Ethics]

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4
Moving Toward Solutions: A Suggested Approach

To reiterate, the foregoing is not a research agenda per se, but a recitation of key problems that reflect the nation's needs and that should drive MOT research in the near term. The research community itself, through established review processes and in conjunction with sponsors, should determine whether specific research topics address these needs productively. At the same time, education programs in MOT must be expanded and restructured, new programs initiated, and an integrated curriculum developed. The growth in MOT must be both rapid and incremental, adding to what already exists in terms of knowledge and educational capability.

To that end, it is recommended that the process of developing the field take the form illustrated in Figure 4A. It should be a continuous and cumulative process in which progress in research adds content to the curriculum and drives the development of needed management tools and insights, which in turn are tested in the real-world "laboratory" of actual industrial experience. The results of experimentation are then fed into the literature and disseminated to industry and government, leading to support for further progress. Figures 4B–D illustrate and expand on two of the major segments of this continuous process.

It is obvious that the field's expansion to meet the needs of industry will depend very heavily on the participation of industry—as the possessor of the knowledge base, as the test bed for research and experimentation, as an implementer of new tools, as

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an employer of graduates trained in the new approaches, and as a supporter of research. Government must also be a key player, especially as a catalyst in providing funding to stimulate initial movement in the process.

Universities clearly have a very important role to play in making the academic environment hospitable to this new thrust. There are presently a number of major academic impediments to progress in the field of MOT. One is the cluster of traditional problems (promotion, tenure, etc.) that face any cross-disciplinary research effort. These problems may be key reasons for the lack of a critical mass of enthusiastic professors interested in working in MOT. However, these problems may be abating somewhat as the national research agenda changes in response to a changing techno-economic environment.

A more serious impediment for the field of MOT is the fact that many untenured faculty are reluctant to do problem-oriented research because of resistance from the university structure. This situation must change. Just as the functional divisions of industrial organizations are altered to allow for cross-functional roles when the rate of techno-economic change accelerates, so too should the disciplinary organization of the university also be altered to encourage cross-disciplinary research when the need to understand these new industrial organizational structures arises. In this new environment, the adequacy of the established disciplines to address the range of current problems is diminished as long as the boundaries of those disciplines are rigidly maintained.

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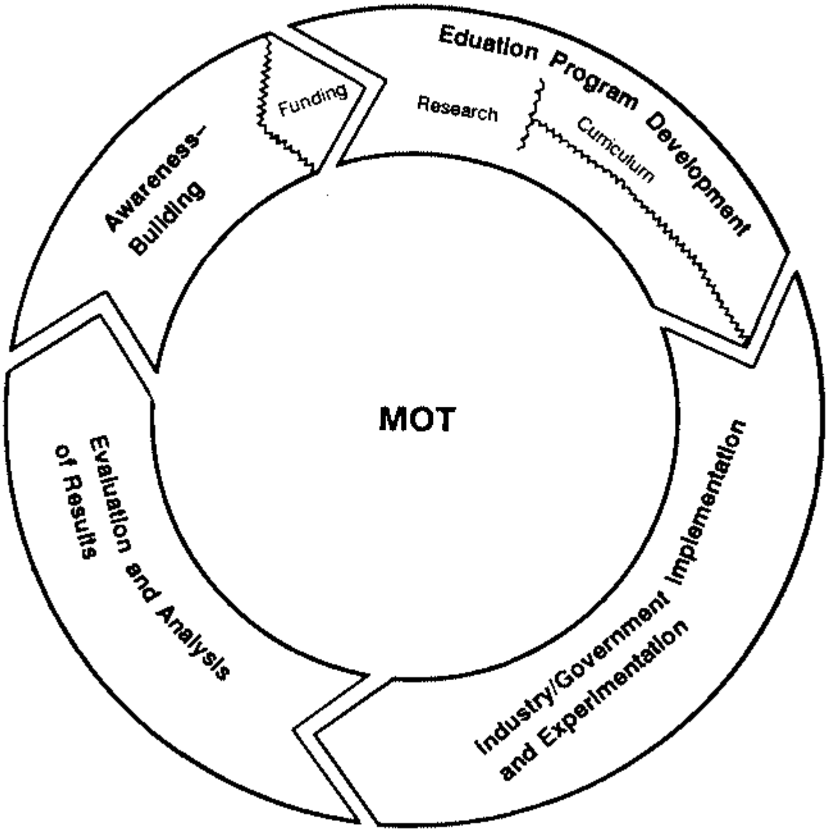

FIGURE 4A Process Overview.

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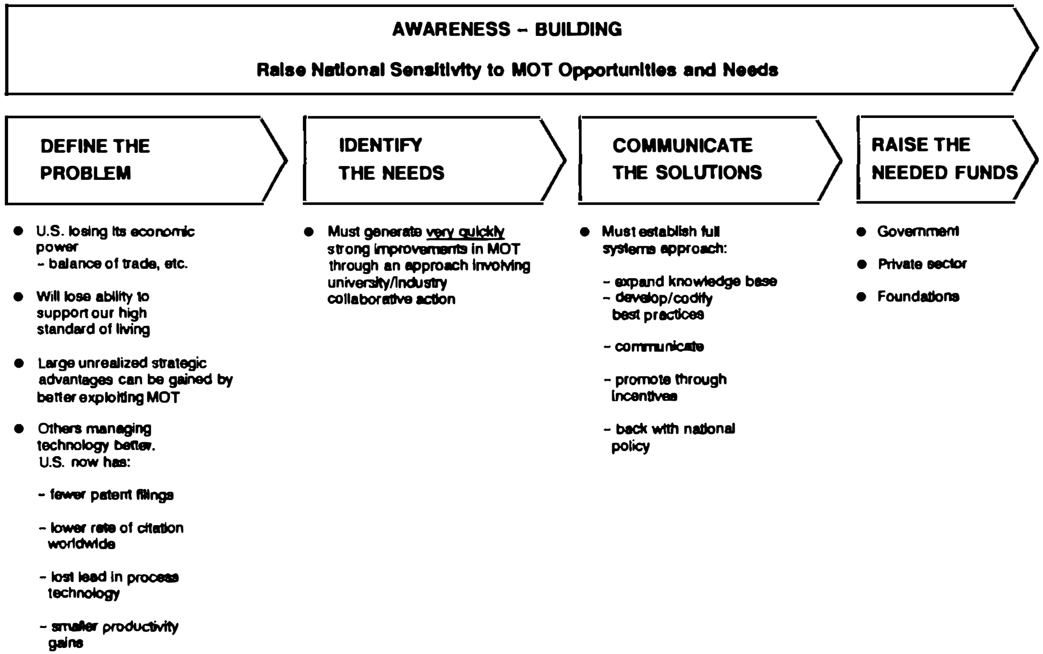

FIGURE 4B Process Overview.

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EDUCATION PROGRAM DEVELOPMENT

Curriculum

FUNDING

SOURCES

- Private sector
  - Industry
  - Foundations
- Government
  - NSF
  - DoD
  - NASA
  - (Other)
  - State/Local
- University

RESEARCH

BROAD TOPICS

- How to integrate technology into overall strategic objectives of the firm (resource allocation, planning, etc.)
- How to get in and out of technologies faster and more efficiently (timing, selection, prioritization, obsolescence, etc.)
- How to perform technology assessment/evaluation (risk, reward)
- How to accomplish technology linking/transfer
- How to shorten product development cycles
- How to manage large, complex, and interdisciplinary projects
- How to leverage the effectivenss of technical professionals
- How to manage the organization's internal use of technology (MIS, CIM, CAD/CAM)

CURRICULUM

- Engineering/Science
- Management
- MOT
  - Strategic/Long term
  - Interfunctional
  - Current RDE&O
  - Technology Support Services

[see Figures 3 and 4]

DISTRIBUTION/ DELIVERY

- Corporate
  - Seminars
  - Mid-career
  - Regular training programs
- Graduate
- Undergraduate

Delivery Agents

- University Faculty
  - as professors
  - as consultants to industry
  - as entrepreneurs
- Industry Educators
  - in-house
  - as adjunct professors
- Management Consultants

FIGURE 4C Process Overview.

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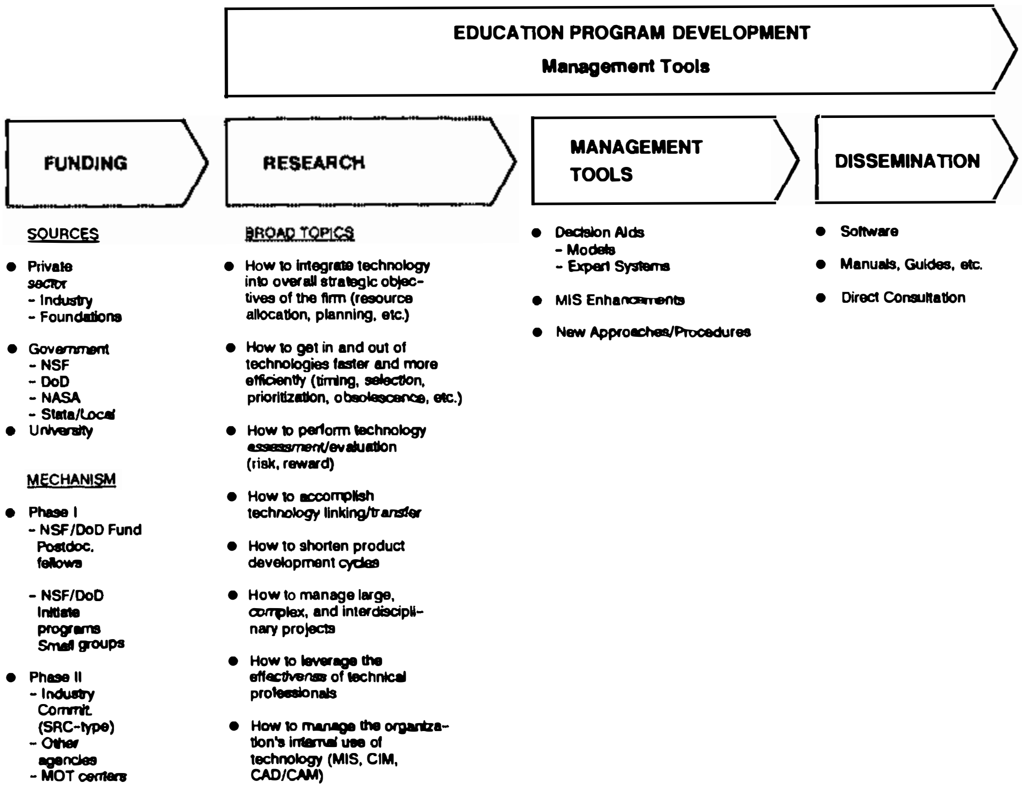

FIGURE 4D Process Overview.

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5
Recommendations

Effective work in the field of MOT can play a crucial role in devising the strategies and imparting the skills and attitudes to U.S. engineers and managers that they will need in the future technology-dominated economy. To be effective, however, strong collaborative efforts among government, industry, and academia will be required. The key will be to build on current knowledge of MOT with new research efforts, and to give the many issues involved in effective technology management more emphasis in the training of both engineers and managers. To succeed, government will need to support research efforts in MOT, industry will need to open companies to the researchers and be receptive to their findings, and academia will need to overcome its traditional biases against interdisciplinary research and education to allow extensive work in MOT.

The following mechanisms are recommended to build awareness and stimulate continued development of the field of MOT. Progress should occur in three phases:

PHASE I: Building National Awareness

The NSF should convey a sense of urgency to the nation's academic and industrial management communities that technology and its effective management will be increasingly important to the competitiveness of U.S. industry and the strength of the U.S. economy. With the cooperation of the National Academies, the

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Conference Board, the Business Roundtable, and other organizations able to disseminate this message, the NSF should emphasize the role of MOT in supporting future progress.

PHASE II: Initiating the Process

1. 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. Support mechanisms should include:

- providing long-term grants to individual academic researchers in MOT;
- funding small-group research (including joint university-industry efforts);
- financial support for masters and doctoral students in specialized MOT graduate programs;
- supporting postdoctoral fellowships in MOT at qualified universities;
- conducting a state-of-the-art review of MOT periodically to assess its progress and directions; and
- stimulating the interest of other agencies by holding interagency conferences and disseminating the results of the funded MOT programs.

Funding should be contingent on the academic researchers having the support of industry in their work.

2. Industry should commit itself to the process in the following ways:

- recognize the potential for MOT to be improved through research and education;
- work with academe in identifying internal corporate needs, both long term and immediate;
- employ graduates with good grounding in MOT and provide them with an opportunity to influence technology-related decisions at levels appropriate to their position in the company; and
- form partnerships with academic MOT researchers—that is, provide funding for research and curriculum development, and make people and facilities available as a test bed for experimentation.

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3. The university community can contribute in the following ways:

- University administrators and faculty must recognize the increased importance and validity of problem-oriented research and education in cross-disciplinary fields, and in their deliberations governing promotion, tenure, and reward.
- Tenured professors in related areas could contribute to the rapid development of the field by focusing their research and teaching on needs identified in this report.
- Researchers active in MOT might benefit from forming a professional association dedicated to the improvement of MOT practice through research and education.

PHASE III: Continuing the Process

1. If the results of Phase II appear to warrant it, the NSF and DOD should consider establishing at universities one or more cross-disciplinary research centers in MOT.

2. If initial results prove valuable, industry should provide more substantial funding for academic research and education in MOT, including, possibly, the establishment of a collaborative funding mechanism for focused research related to MOT—perhaps using the Semiconductor Research Cooperative as a model.

3. With the NSF as the catalyst, and with the DOD and NASA as leaders among the mission agencies, other government agencies involved in technology development (e.g., the Departments of Energy and Commerce), as well as private foundations, should initiate their own programs to support work on MOT.

4. If initial results prove valuable, an aggressive dissemination program should be established, including a large case library, the writing of textbooks, and so on, to develop the body of knowledge that could be readily incorporated into industrial and academic education programs.

Although these recommendations may appear to represent slow movement toward improving our understanding of the many aspects of the technology development and implementation process, they represent an orderly and efficient methodology for developing the necessary knowledge base. These recommendations can be the beginning of a major national initiative; the speed with which it materializes depends directly on the funding and resources made available, and their timetable.

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