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RESEARCH ON THE HUMAN FACTOR IN THE TRANSFER OF TECHNOLOGY*

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RESEARCH ON THE HUMAN FACTOR IN THE TRANSFER OF TECHNOLOGY

by

William H. Gruber* Donald G. Marquis#

ABSTRACT

This concluding chapter in the proceedings of the MIT Conference on the Human Factor in the Transfer of Technology summarizes and integrates the findings of the papers presented at the conference. The disparity between the current state of knowledge about the human factor in technology transfer and a preferred state is specified in a series of questions that were raised at the conference. The research frontier is described; definitions of terms are suggested for further research efforts, and models that specify the critical problems for further investigation are presented.

The summary of the current state of knowledge indicates that better understanding of the technology transfer process has the potential for a significant increase in the economic value of technical knowledge, due to the observed phenomenon that technical advance is based largely on readily available technical knowledge. The process of fusion of "demand recognition" (defined as a perceived disparity between an actual and a preferred technological capability) and "technical feasibility recognition" (defined as the perception that technical progress can be achieved) is described, and the role of this fusion (defined as "design concept") in the process of technical advance is analyzed.

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The human factor determinants of the ability/willingness to have the recognition necessary for the achievement of design concept are summarized under the following categories of effect: (1) training and experience, (2) individual personality characteristics, (3) communication patterns, (4) organizational effects, (5) mission orientation, (6) motivation. The findings that have been presented are then used to study the science-technology relationship.

INTRODUCTION*

Technology may be defined as the means or capacity to perform a particular activity. The transfer of technology must then mean the utilization of an existing technique in an instance where it has not previously been used. This transfer may be merely the acceptance by a user of a practice common elsewhere, or it may be a different application of a given technique designed originally for another use.

The acceptance by a user of a common practice is called "adoption," and the spread of such adoptions the "diffusion of technology." The application of technology in a new way is properly labeled an "innovation."** A transfer of technology occurs in both adoption and innovation in the sense that a decision is made to use a form of technology where it has not previously been utilized.

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* This chapter summarizing and integrating the findings presented in papers given at the MIT Conference on the Human Factor in the Transfer of Technology will refer to the papers given at the conference by reference to the author of the paper. Citation to findings in the published literature will be given in the reference section at the end of this paper.

** Some studies (e.g., Myers, 1967) have called an "innovation" any new utilization of a technique in a firm whether or not the technology was commonly used in the industry in which the firm was located. As far as the situation internal to the firm is concerned, this does represent an "innovation." A process study of the transfer of technology can be conducted more efficiently if the distinction between innovation and diffusion of technology is made explicit, as suggested in this paper.

Note that a form of use occurs in both cases. If technical elements are brought together in a new way and a new technology results, this would be called an "invention" until it is used to satisfy a demand, at which point an "innovation" occurs. Research on the transfer of technology thus focuses on "innovation" and "diffusion" because the word "technology" connotes a method of achieving a practical purpose or "use."

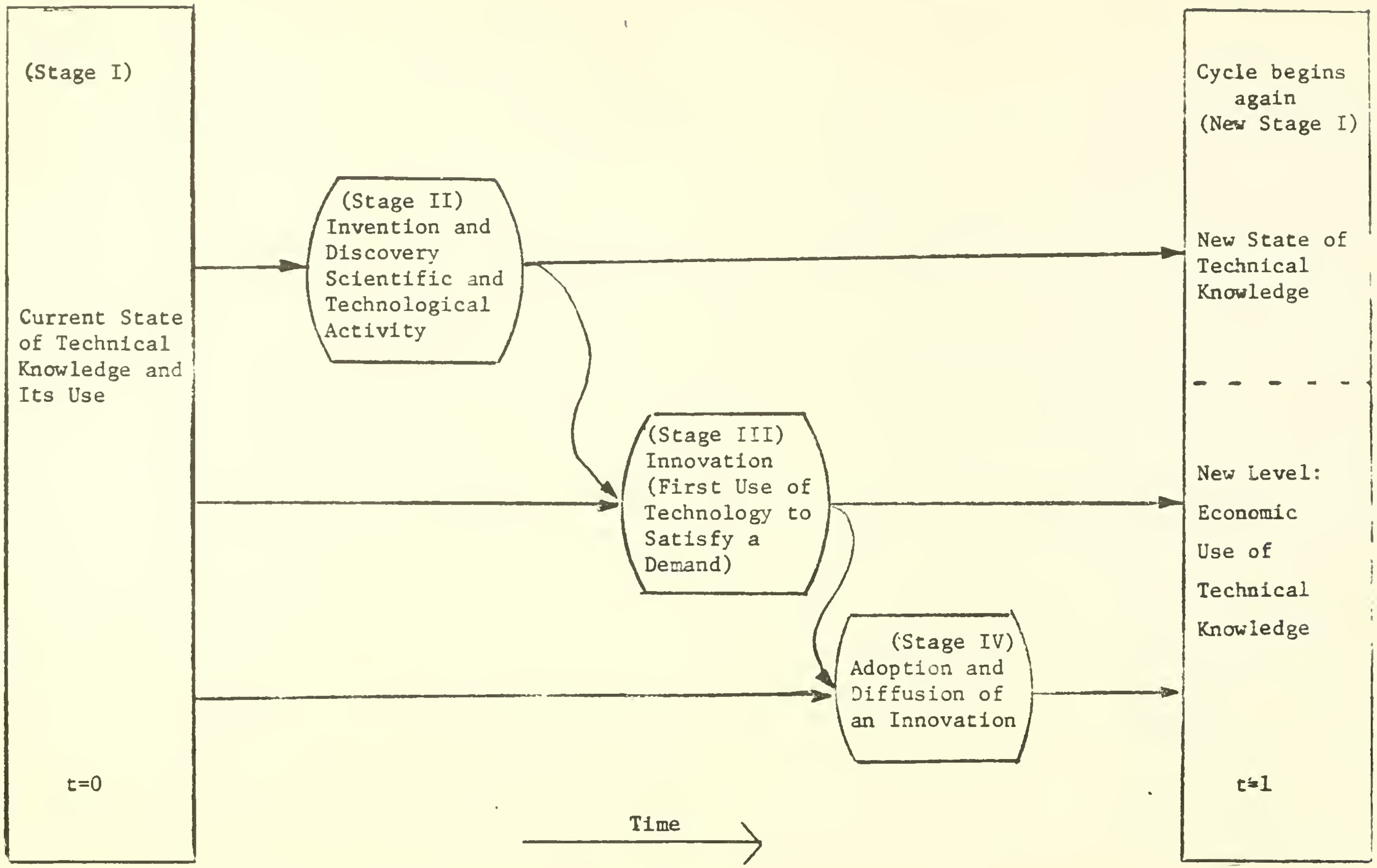
"Use" requires at least one user in the broad economic meaning of the word. A product must be sold, a piece of equipment must be used, or a unit of military weaponry must be put into production in order to qualify as examples of transferred technology. The economic meaning of "use", therefore, connotes utilization to satisfy a demand or need for a product or service.

THE PROCESS OF TECHNICAL ADVANCE

Morton (1967, p. 153) has described the millimeter wave transmission project in Bell Telephone Laboratories as a "serious failure" because the economic need had not yet appeared despite the technical progress made in the project's life span of 30 years. It is possible to have "technical advance" without economic use as illustrated in Figure 1, a four-stage diagram of technical advance.

Figure 1 demonstrates that at a given point in time (t=0) there exists a state-of-the-art situation or inventory of technical knowledge. This technical knowledge is embodied in various economic uses, and these uses may be tabulated at a given point in time (stage I, t=0).

Figure 1. A Four-Stage Process of Technical Advance*



* Technical advance defined as an increase in the level of technical knowledge and/or an increase

Stage II indicates activity to advance the level of technical knowledge by means of invention and scientific discovery. There may be an increase in technical knowledge in stage II that will never reach utilization. This technical advance would, therefore, not enter into the magnitude of economic value calculated for the use of technical knowledge. There may be transfer of technology from stage I to stage II, but this transfer will not have an economic value until there is a use resulting from it.

If the technical advance achieved in stage II reaches at least one economic use, then innovation takes place, and the process moves into stage III, a first use of a technical advance. The transfer of technology used in the inventive stage now achieves an economic value. Until stage III is reached, there can be no economic value to a transfer of technology. It is now possible to trace a transfer of technology from stage I through the invention activity in stage II and then into stage III where the technology transfer attained an economic value as an innovation. After stage III has been successfully reached, the economic value of the technology transfer will be increased as multiple uses (diffusion) of the innovation take place.*

The macro-economic value of the technology transferred is determined by the activity in stage IV. Each adoption in stage IV represents a technical advance for the economy as a demand is satisfied by a good or service embodying the use of the technical advance.

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* Toulmin described the process of technical advance with an analogy from zoology: mutation, selection, diffusion, and dominance. The measurement of value in economic terms permits the same cycle suggested by Toulmin. Economic motivation leads to attempts at achieving dominance through efforts at the earlier stages of technical advance diagrammed in Figure 1.

The introduction of diesel locomotives provides a good example of the process of technical advance (cf. Hogan, 1958). A switching diesel with inadequate power was developed by a combination of Ingersoll-Rand, American Locomotive, and General Electric. Ten railroads tried it before the first sale was made to a railroad in 1925. The Electro-Motive Division of General Motors began work on diesel locomotives for line use (distance hauling in contrast to yard switching) when most of the needed technology was in stage I. The General Motors effort was initiated at the request of Ralph Budd, a railroad executive who was concerned about the loss of passenger business. The initial innovation, the use of the first line diesel by the railroad managed by Ralph Budd, occurred in 1934. Relative to the ease of this innovation, the process of diffusion was difficult because of the resistance of railroad management.

General Motors used a number of techniques to achieve diffusion. Guarantees of improved performance, the loan of diesels when a sale could not be made, agreement to give maintenance at a rate half the cost of maintaining a steam locomotive, and long-term credit terms helped to facilitate diffusion.

It is important to differentiate the innovator (stage III) from the adopter (stage IV). It takes more courage, foresight, imagination, and willingness to take risks at stage III than at stage IV. The experience of the innovator is available to the adopter.

An increase in technical knowledge is expected to result from activity in stage II. It is probable that many innovations that represent technology transfer from inventory (stage I) to first new utilization (stage III) will also stimulate an increase in the inventory of technical knowledge as a result of the experience gained in working with a new use of a given kind of technology.

Three time periods are identified in Figure 1. Technical advance and the processes of technology transfer and utilization are, of course, continuous in nature. The three time periods are defined for purposes of analysis. It is possible to examine the inventory of technical knowledge and the economic value of the utilization of technical knowledge at a point in time (t=0), and advances above this base period can be studied (stages II, III, and IV). For any given event, the timing of the stages is a useful form of presentation. For total activity during the period lasting from t=0 to t=1 all three stages of activity occur simultaneously.*

INVENTORY OF TECHNICAL INFORMATION**

The value of the available technology for both invention and innovation is clearly demonstrated in many studies. From Table 11 of Allen's paper, it is possible to calculate that only 73 of 276 messages accepted (technical information used) were products of analysis and experimentation. All other accepted messages were examples of the utilization of available technical

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* In fact, the inventory level stage I can be conceived as moving across the period in real time terms. The first difference presentation of the process can be converted into a continuous function once the process is understood.

** This phrase is used rather than the common use of the words "transfer of technology" to describe the phenomena under investigation. "Technical information" (whether embodied in words, ideas, or physical objects) appears to be a better description of what is transferred. The more general concept will be used frequently because of the fact that it is difficult to separate applied science from technology. "Technical information" and "technology" will be used interchangeably in this chapter because of the acceptance of the word "technology."

information.* Tanenbaum (1967, p. 152) reports that "available knowledge" was of critical importance in the majority of the samples of innovations studied by the Materials Advisory Board of the National Academy of Sciences. Myers (1967, p. 140) reports that two-thirds** of the technical information needed was readily available to the innovators in the sample of 567 commercially successful innovations identified in his study of 121 firms in three industries.

One might expect that if a given unit of technology were available, people with problems to solve would seek it out, and the question of the transfer of technology would be one of somehow indexing available technology to provide easier access. The MIT Conference was initiated on the assumption that the limitations of transfer were not due to the failure in some mechanical screening process. Instead, the problems of technology transfer were conceived as resulting from the relationship of people to the technology utilization process.

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* It is not possible from Allen's research to determine the proportion of the accepted messages that resulted from analysis and experimentation that might have been discovered through the other sources of information in his analysis rather than through actual research efforts. That is to say, it is probable that not all of the 73 accepted technical messages from analysis and experimentation had to come from that source, had better utilization been made of existing technology.

** About half of the innovations were based on information available within the innovating company; half used information sources external to the company.

The inventory of available technology increases as a function of time and of the number of people involved with inventive effort. A small increase in the rate of technology transfer (i.e., an increase in the speed and amount of utilization of available technology) would clearly be of enormous consequence. Despite the benefits that might be expected from an increase in the use of available technology, research on the development and utilization of technology is of recent origin.

UTILIZATION OF EXISTING TECHNICAL INFORMATION

The ability and the willingness to discover and use available technical information varies among countries, among industries and regions within a country, among firms within an industry, and among technical personnel within a firm or geographic region. Performance has been found to vary over time even within the same industry in the same country (e.g., Gruber's report on the rise and fall of the steel industry in the United States). It is now important to seek the determinants for the variance in the utilization of available technology.

A review of the papers in this volume provides examples and sources of explanation for some categories of this variance. McClelland noted that scientists are educated in such a way as not to seek practical use from their discoveries. Empirical support is furnished by the finding reported by Roberts that scientists (those educated with a Ph.D.) tend not to be as successful in founding businesses as are technical personnel with lower levels of educational attainment.

The variance among firms in the use of technology was noted by Burns and Stalker (1961) and Carter and Williams (1957). Gellman (1967) posits that innovative firms and industries tend to deal with similar firms and industries because of the difficulty in selling new technical ideas to firms with low ability or willingness to innovate and accept new technology. This may contribute to an explanation of why whole industries (such as the steel industry in the United States) in a relatively innovative country may fail to respond to new technology. An industry may get the quality of suppliers or supporting industry that it deserves. This phenomenon may also explain differences in country-wide performance such as have been evident in the failure of France relative to Germany to achieve exports of technologically intensive products (Gruber, Mehta and Vernon, 1967).

It is apparent that the ability/willingness* to achieve technology transfer can determine the relative success of industries or countries. When the focus of attention shifts from the ability to develop new science or technology to the question of the ability/willingness to utilize new technology, then a different way of keeping score becomes necessary. As Toulmin noted in his paper, the fact that an invention developed in Britain (the Hovercraft) was put into first commercial utilization by a Swedith firm may be an indication of a weakness in the orientation of British industrialists which may offset the strength of inventive capabilities manifest in the technical development of the Hovercraft.

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* The concept of ability/willingness to innovate has often been expressed in the literature as "resistance to innovation." Due to the fact that there are positive as well as negative values in the ability/willingness to innovate, the use of "resistance" gives an unbalanced impression of the phenomenon.

The value to be derived from an increase in the efficiency of technology transfer leads to an interest in the determinants of variance in transfer capability. The MIT Conference focus was on the human factor, and it is obvious that no technology transfer occurs without human activity. A total set of determinants of the ability/willingness of humans to transfer technology must include economic variables, such as competitive pressure, capital resources, market potential, etc., that were analyzed in Gruber's paper. The focus on the human factor provides a study at a lower level than that of a total systems analysis. Progress at this level is, however, necessary to provide the values for a more complex, higher-order analysis, given the short history of research on this problem and the paucity of verified findings.

RECOGNITION OF DEMAND AND TECHNICAL FEASIBILITY

The first step in the process of utilization of technology is demand recognition. This is in harmony with the idea expressed by Pounds (1965) that the solution to a problem is conditional on problem identification. Some precise definitional considerations are necessary before this basic concept of demand recognition can be used.

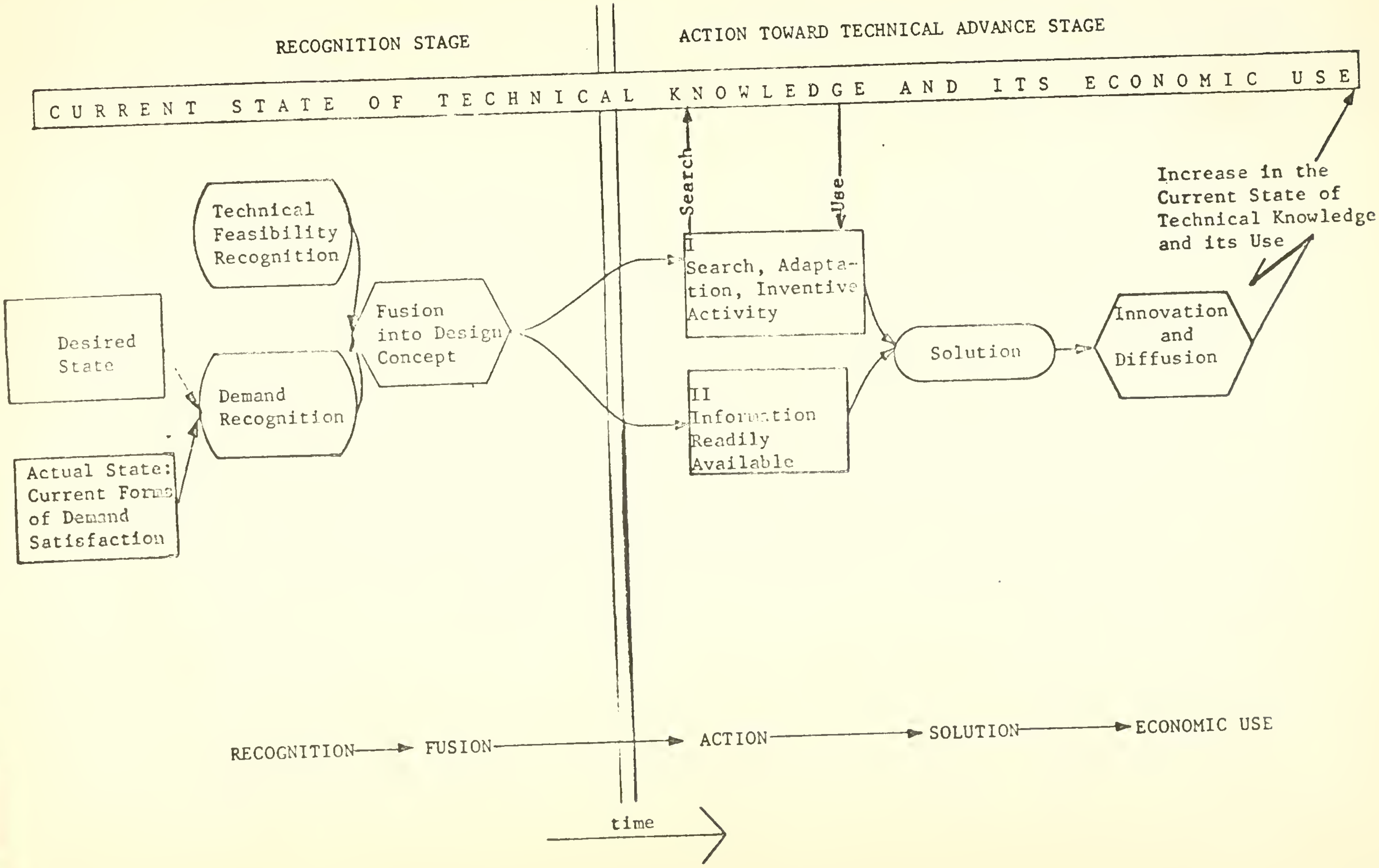
A more common expression is need recognition. Needs are infinite. There must be a willingness to act, to allocate resources to meet a given need, before need is translated into demand. For example, Galbraith (1958) in The Affluent Society, expressed the opinion that there was a need for public sector services that was not being met because of the values of those who influence resource allocations between public and private sectors. At the time of Galbraith's book, these needs were not expressed as demands and funds were not supplied for such activities as air pollution control, education of the poor, and health services for the aged. Everyone has a need for something more than they have; demand represents the choices that are made giving a funding constraint.

A critical factor in technology transfer is, therefore, the recognition of demands that are not being satisfied by the technology currently in use. A second factor is the recognition of technical feasibility.

Technical feasibility recognition is defined as the discovery that available technical information (with perceived modifications) would provide a new technical capability. This does not indicate that a potential use (*i.e.*, demand recognition) has been identified. Large expenditures are made in fields such as heavy particle physics and lasers because of technical feasibility recognition despite the failure to link the expected advances in technical capabilities with specified uses that are based upon demand recognition.

Innovation is most likely to be initiated when recognition of a demand and a feasible technical solution for the specified demand are *fused* and a satisfactory technical response to a user requirement becomes available. Figure 2 diagrams this process of fusion, occurring before search and inventive activity has been undertaken. Other diagrams would be necessary to illustrate situations where demand and technical feasibility recognition were not simultaneous as indicated in Figure 2. Demand recognition may result in the initiation of inventive behavior without technical feasibility recognition (*e.g.*, the national cancer research effort). And, as indicated in the example of the heavy particle research program, technical feasibility recognition may result in the funding of inventive effort without a perceived economic demand for the results of the expected technical progress.

Figure 2: Technical Advance (at a micro level) Related to Demand-Technical Feasibility Fusion



The demand-technical feasibility fusion phenomenon as illustrated in the micromodel of technical advance presented in Figure 2 may result in two further stages of action. Further search, adaptation and inventive activity (noted as I) may be necessary, or a solution may be conceived without a significant input into further search and inventive effort (diagramed in flow II of Figure 2).

If demand-technical feasibility fusion occurs successfully (i.e., the perceptions of demand and technical feasibility are accurate), then innovation and diffusion of innovation will occur.*

Demand recognition results from an awareness of a desired state that is superior to the actual state for the satisfaction of a specified demand. In order to make the concept of demand recognition or the concept of fusion into design concept operational, it is necessary to specify how such actions occur.

Take, for example, Goldmark's invention of the long-play microgroove record. It has been reported that Goldmark experienced demand recognition when he was listening to Horowitz playing Brahms and was annoyed when his pleasure ended with a click of the 78 r.p.m. record at an inopportune time. Goldmark then invented the 33 r.p.m. record (Edson, 1967, p. 82). It is

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* A more complex model should take into account economic factors such as the resources of the organization in which the demand-technical feasibility fusion occurred. The ability/willingness to achieve the diffusion of a successful demand-technical feasibility fusion may require resources that are not available to the innovator. Demand may be latent, and have to be created in order to achieve the full economic potential of the innovation. The micro model in Figure 2 concentrates on the first three stages of Figure 1

probable that there were many music lovers before Goldmark who were enraged by the limitations of the 78 r.p.m. record system. But Goldmark did something about the problem, and he is credited with demand-technical feasibility recognition.

A perception rated as demand recognition clearly <u>requires some effort</u>* or response to the perceived demand. The person credited with demand recognition must initiate action to move toward a perceived preferred state. Design concept also requires action in order to bring an improvement based upon demand and technical feasibility to some observable level of technical realization closer to an innovation than existed previously.** Ability/willingness to take action, as defined at the MIT conference, is thus an indispensable factor in the process of technology transfer into utilization (stages III and IV of Figure 1).

The combination of design concept and ability/willingness to take action is described by Morison (1966, Chapter 2) in his "Gunfire at Sea" example. It is probable that the inaccuracy of naval gunfire had been recognized previously.*** But it was Sir Percy Scott who invented continuous-aim firing. The example illustrates two ideas. First, all of the technology needed for continuous-aim firing (telescope, elevating gear,

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* An important area for further research would be on the identification of situations where some form of demand identification is expressed and no action is taken.

** It is insufficient to work toward an invention without a specified demand in mind. It is for this reason that the requirement of moving closer to an innovation (a use) than to an invention (a technical advance) is specified as necessary for design concept recognition.

*** Morison (1966, p. 22) reports that, "In 1899 five ships of the North Atlantic Squadron fired five minutes each at a lightship hulk....After twenty-five minutes of banging away, two hits had been made on the sails of the elderly vessel."

the gun) was readily available. Second, the combination of fusion into design concept and ability/willingness to respond had to exist. Examples cited earlier show that there can be design concept fusion resulting in invention without the ability/willingness to respond to demand by achieving innovation and its diffusion.

The micro process in Figure 2 may be related to the structure of the process of technical advance presented in Figure 1. The current state of technical knowledge and its use is the same concept in both cases. Naturally, interest at the micro level in Figure 2 is with a specific subset of the total as presented in Figure 1. A movement from stage I to stage III as diagrammed in Figure 1 is similar to the case II situation in Figure 2, because in both instances the needed technical knowledge is available.

The relationship between Figures 1 and 2 permits the integration of most of the available research on the process of technical advance and technology transfer.

The process of technical advance vis-à-vis the utilization of the inventory of available technical knowledge is a function of: (1) demand recognition; (2) technical feasibility recognition, and (3) the ability/willingness to achieve utilization provided by recognition and subsequent development of a solution. What are the determinants of these three factors in the transfer of technology into new uses? How do the determinants vary by level of organization? These two questions are presented in Figure 3 where the determinants of recognition and ability/willingness are related to the level of organization under investigation.

The specified cells in Figure 3 have been left empty because of the paucity of information currently available on the problem.

The work of future research on these questions may well be conceived in terms of completing the gaps that are structured by Figure 3. The present low level of understanding of the process leading to the utilization of new technology has serious consequences. It is possible to cite innumerable examples of failures or lost opportunities that have resulted from the fact that these most basic elements in the transfer of technology are, in practice, almost a random process.*

HUMAN FACTORS IN TECHNOLOGY TRANSFER

The process of technology transfer from inventory to utilization (from stage I to stages III and IV in Figure 1) is a sequence that often passes through inventive activity (stage II in Figure 1). Figure 2 presented a micro model in which demand and technical feasibility recognition fuse in design conceptualization. Figure 3 shows that research on the problem should include different levels at which the factors of demand-technical feasibility recognition and ability/willingness combine to achieve utilization. Given the cells created by Figure 3, the available evidence will be presented for the following determinants of technology transfer:

(1) Training and experience
(2) Individual personality characteristics
(3) Communication patterns
(4) Organizational effects
(5) Mission orientation
(6) Motivation

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* An enumeration of examples would include the following kind of experience. The possible use of estrogens (part of the steroid class of drugs) for birth control was not recognized until recently. Early in the 1950's women were warned not to take certain drugs because of the antifertility effect. That this side effect was considered a deterrent to the sale of this class of drugs rather than a potential finding for a major market need is an example of both the nature and the importance of the demand recognition phenomenon.

Figure 3: Determinants of demand and technical feasibility recognition and ability/willingness to achieve utilization given a solution by level of organization

	DETERMINANTS OF			
	RECOGNITION OF			
Level of Organization	Demand	Technical Feasibility	Inventive Activity*	Ability/Willingness to Utilize a Solution
Individual				
Group or Operating Unit				
Firm				
Industry				
Nation				

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* Where necessary. Figure 2 made manifest that inventive activity may not be necessary to achieve a solution given demand and technical feasibility recognition.

Although these factors will be presented separately, they are interrelated, and it is not possible at the present level of understanding to clearly separate the effects where causation appears to result from several factors. Available research is not adequate to complete the cells created by Figure 3. It is, therefore, not possible to divide the findings by the level dimension.

A far more complex structure could have been presented. Ability to respond is clearly a different concept from the willingness to respond. Recognition of demand and recognition of technical feasibility are associated with different human factor considerations than the process of fusion in the design concept. The available findings tend to be partial in nature and do not complete any dimension of this structure. A major contribution of the following review of findings is that it serves to illustrate the quality of information that is needed for a more complete understanding of the determinants of the recognition and the ability/willingness aspects of the human factor in the transfer of technology.

1. Training and experience: Since many innovations are achieved on the basis of readily available knowledge, it follows that the training and experience of the persons involved would be a critical factor. When search is required for invention, the same qualifications would be essential. One of the most generally accepted propositions put forward at the conference was aptly summarized by Burns: "The mechanism of technological transfer is one of agents, not agencies; of the movement of people

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* Note that these determinants are limited to the human factor facet of the question. Economic factors are discussed in Gruber's paper

between establishments, rather than the routing of information through [formal] communications systems." Derek Price noted in his paper that engineers tend not to write, and thus applied technology of recent vintage is not in the literature. Engineers, according to Allen, also tend not to read. The trend toward greater specialization of technical effort, the increase in the volume of technical information, and the speed of technological advance are all factors leading to the idea that it is more efficient to bring into an organization someone experienced in a given technology than to try to develop expert personnel in an organization. Research results on this practice were not reported at the conference, and the evidence that was given tended to be case experiences.

Research on this phenomenon would also be of value at the international level. It is alleged that mobility of personnel (movement from one organization to another or movement within an organization) is of value in itself. Europeans have begun to think of employment stability (firm loyalty) as a possible factor in the technology gap. There is enough contrary evidence* (such as the stability of employment in Japan, a country noted for the speed with which technology is transferred from foreign

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* The personnel identified as sources of events in the Project Hindsight study moved less frequently (only 45 percent reported more than two employers) than the average of technical personnel in industrial research laboratories (75 percent). (Personal communication from Raymond Isenson after the conference.)

sources to domestic utilization) to indicate that further research on this facet of the usefulness of personnel transfer is warranted.

Allen's paper presented evidence that internal sources were more effective in generating useful technical information than sources external to the firm. He explains this finding in terms of the development within a firm of a communications coding system that facilitates the transfer of technical information. Both the training and experience of technical personnel are involved in this finding. A consequent personnel strategy would be to have staff in a firm that was equal in breadth to the technical needs of the research to be undertaken -- in contrast to reliance upon outside consultants or contractors for areas of technical weakness.

The usefulness of scientists working on applied projects in industry is evidence of the training-experience effect. Scientists have had different training from that of engineers. Reiss pointed out that scientists working in a firm are able to become aware of the problems or needs toward which they can apply their specialized training. Allen's findings on the importance of a common code for discussion and Reiss' report on the process by which scientists and engineers communicate within a firm should be viewed as two facets of the same phenomenon.

Studies of the experience effect indicate that age (years of experience) is of critical importance. Apparently a number of years is required before a technically trained person is likely to contribute to significant technical events. The average age of Hindsight personnel identified with critical advances in technology was

34 years.* Roberts reported the average age of entrepreneurs as 32, and Pelz and Andrews (1967) found that the productivity of scientists and engineers did not reach a maximum before age 35 to 40.

The role of training is demonstrated in the findings reported by Isenson* and Tanenbaum (1967) that critical inventions were contributed in much greater frequency by personnel with higher levels of education (above a bachelor's level) than would be expected by the proportion of advanced degree personnel working on technical projects.

Shapero was able to relate the level of educational attainment and the average age of scientists and engineers to the nature of the technology in his study of differences in regional resources of technical manpower. He found that regions where the newer, more advanced technology was concentrated had technical personnel with a higher average level of education than that of personnel in regions with older, less dynamic technology. The personnel in the regions with the new technology tended to be younger than the personnel in regions with less advanced technology. This indicates that the flow of personnel with advanced training from schools is directed toward regions requiring younger personnel trained at the frontier of new science and technology. Shapero's findings provide insight into the importance of the educational process in responding to the needs of advanced technological activity

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* Personal communication from Raymond Isenson subsequent to the MIT conference.

Price, et. al. reported on the efforts of the Air Force Office of Scientific Research (AFOSR) to assist in the process through which work at the technological frontier is performed by personnel educated in the required new science and engineering. The AFOSR identifies new areas of science and engineering for which personnel will be required for the success of Air Force R&D projects. Then AFOSR funds research in the universities that helps to develop the personnel with the expected new educational experience and training.

2. Individual Personality Characteristics: Frustration tolerance, need for achievement, and other such personality traits clearly vary between individuals, and classes of individuals (explained by family background and other such conditioning socio-economic variables). Roberts' findings of the age, need for achievement, and religious background variables associated with the successful formation of new technical enterprises by entrepreneurs would be examples of this determinant of recognition-ability/willingness to respond.

The ability to formulate a design concept, the fusion of demand and technical feasibility recognition, is one of the rare gifts about which little is known at the individual personality level. The question of individual personality characteristics is related to other determinants such as organizational environment, as Pelz and Andrews (1967) have indicated.

Morison (1966, pp. 24 and 27) describes the innovators of continuous firing at sea in Britain and the United States, Scott and Sims, to be men who were intolerant of bureaucratic inertia.

Schon noted that the transfer of technology was an activity that required a high level of motivation due to the difficulties inherent in the process. Efforts have been made in a number of firms to reduce the barriers to innovation. Further research on the personality characteristics of individuals with a high propensity for demand-technical feasibility fusion and the ability/willingness to respond would assist such efforts at organizational improvement.

3. Communication Patterns: Allen reports on the effect of a common coding system within a firm in providing useful technical information. Myers (1967) reported the importance of the transfer of technical information external to the firm as a critical source of innovation. Meadows and Marquis (1967, p. 16) reported that the commercial value of R&D projects initiated by marketing and customers was far greater than that of projects initiated within R&D. Cochrane (1967) reported that firms where non-R&D managers were more involved with the control of R&D were rated as having more effective R&D efforts (and, therefore, more transfer of technology into utilization) than firms where more of the control of R&D was maintained by R&D personnel.

These findings relate to the required fusion of demand and technical feasibility recognition. Communication within a firm and to the external environment are found to have explanatory power when differences in performance have been identified.

In a recent survey of the relationship between R&D and other corporate functions,* it was discovered that only 9 of 25 firms had recognized the importance of this communications factor by setting up a permanent group to coordinate R&D with other corporate functions.

An unusual illustration of the process of communication patterns in the introduction of new technology was reported by Black in his study of the effect of Government funded R&D on the management of commercial R&D. Black noted that the experience of doing Government funded R&D in the same laboratory with commercial R&D led to a spillover of Government-required managerial technology into the commercial R&D activity. This finding is in harmony with Allen's work on the development within a firm of a common coding system for communication. Once a new practice has been brought into a firm, such as managerial technology required as part of Government-funded R&D, then diffusion is much easier than in situations where new technology must be brought in from outside the firm.

4. Organizational Effects: Research by Jewkes, et. al. (1959) and Hamberg (1963) indicates that major inventions rarely occur in the large firms that service an industry and that, in fact, major inventions most frequently are a result of activity from sources

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* Part of a study of relationships between R&D and other corporate functions conducted by one of the authors.

other than the industry most involved with the application of the invention.*

How can this source of major innovations outside of an industry be explained?** Three hypotheses have enough merit to warrant further research on this question. The first is the resistance to change within an organization. That is, once an activity has become established with a given pattern, the response of the power structure in an organization is to reject innovations that would alter the existing activities. Roberts in his paper reported of attempts within large corporations to encourage entrepreneurship in order to remedy this resistance to change. A second hypothesis is that people trained to do a job one way will not experience novel demand-feasibility recognition. A third hypothesis is that organizations acting in a given way have a vested interest (because of capital investment and other considerations) in maintaining the status quo. For example, if an innovation will make obsolete what an organization is doing,

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* The finding on the source of invention or innovation should be considered together with the ability to achieve utilization factors. There may be diseconomies to scale in invention and economies to scale in marketing. If size has a positive effect for one kind of activities and a negative effect in another class of activities, then the net effect should be considered when judging the question of economies of scale. If the net effect is to form larger firms, then correction of the diseconomies to scale problem of a functional activity (such as invention or innovation) is necessary because the trend will be toward organization of larger size.

** See the Department of Commerce Studies (1963 and 1967) for an extended analysis of this phenomenon. Note that there is a difference between demand recognition or technical feasibility recognition and the ability/willingness to achieve the diffusion of an innovation. See Gruber's paper for the economic advantages that are related to size of firm or the ability to achieve utilizatio question.

it may pay <u>in the short run</u> to continue that activity rather than to accept the innovation. This opens the field to innovators outside the organization or industry.

The involvement of non-R&D personnel in the management of R&D need not reduce flexibility in the management of R&D. Improved understanding of the requirements of R&D function is often associated with involvement of non-R&D managers. The Hindsight work reported by Isenson and the Materials Advisory Board study reported by Tanenbaum (1967) illustrates the importance of communication which provides for flexibility of funding and objectives. These reports found that flexibility of funding and objectives was associated with the utilization of new technology (in 76 and 80 percent of the reported cases, respectively).

5. <u>Mission Orientation</u>: Organizational effort allocated specifically for the purpose of discovering demand situations to which the organization is best able to respond, and the development within an organization of a commitment for the translation of demand recognition into organizational action, is perhaps the most efficient way to achieve a technological response to a given demand. The allocation of resources to this process appears to be a useful form of investment. The sources of important technical contributions to a system given in Isenson's paper indicate the value of system definition in the utilization of new technology. Isenson reported that 64 percent of all the critical technical events in his study resulted from the specification of a DoD systems analysis. A further finding was that 37 percent of all events occurred in a late stage (engineering development) of the effort when demand was easiest to recognize.

If a firm can respond to a commercial market, then demand recognition can be fostered through market research that should attempt to link the technical, marketing, and other firm resources with the demand from customers for products or services that are presently unavailable. A major problem has been the inadequate attention given to the required communication between marketing and technical personnel in order to create an internal structure favorable to demand-technical feasibility fusion.

The difference between progress in science and progress in technology can be better understood through analysis of a concept of Derek Price. Price developed the idea that technological advance flows from technological activity in a manner similar to that in which new science flows from old science. He was not able to document the technological advance hypothesis with the literature count technique that he used in his studies of scientific effort (c.f. Price, 1963).

The science frontier tends to shift as new paradigms are discovered for the solution of problems. Technology is directed more by economic value, and it would be expected that technological progress could be predicted better by the shifts in the demand for different kinds of technological requirements.

When demand creates the awareness of a need for new technology, that appears to be a major factor in the discovery and utilization of new technology. Myers* found in his study of 567 industrial innovations that the personnel in the firms were working "actively"

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* Personal communication subsequent to the MIT conference.

with "high priority" in 38 percent of the situations, and "active work" with "low priority" was present in an additional 35 percent of the cases. Thus, recognized need that leads to active search or inventive activity appears to be a critical determinant of technological advance.

The Department of Defense does not have a commercial market to which it can respond. As a consequence, DoD has devoted far greater attention than private industry to systems analysis for the specification of future weapons. The internal structures within DoD that provide systems development services have attempted to link technical resources, financial consideration, and perceived capabilities to meet perceived military needs (a proxy for the market demand of private industry). This mission-oriented systems development program increased the probability of design conceptualization because demand and technical factors are considered simultaneously Available technology reduces the estimated cost of a new system and, therefore, the probability of technology transfer is increased because of comparisons between costs and benefits from various alternative funding decisions for new weapons development.

Technology transfer that results in economic utilization (stages III and IV of Figure 1) was the primary focus of the conference. It is relevant, therefore, to note that demand (the decision to utilize) is a function of technical and cost factors. Mission orientation that specifies the value system of the user stimulated the establishment of technical and cost requirements to achieve utilization. The education of engineers tends to emphasize the technical facet of the mission, and it is useful to define mission orientation in terms of sales dollars of utilization rather than the solution to a technical problem. Recognition of organizational objectives, in contrast to functional objectives, through mission orientation should increase the motivation to work toward the fulfillment of the appropriate objectiv

6. Motivation: This determinant of recognition and ability/willingness to respond permits a systems analysis of individual and organizational behavior. Motivation as a force may be divided into four facets for consideration: (a) competition; (b) the reward structure, (c) visibility of results; and (d) government regulation.

The expectation that competition will innovate first and gain an advantage provides a mental set that increases the awareness of customer requirements that leads in turn to demand recognition and the ability[*]/willingness to achieve the utilization of new technology. Reward structure becomes a motivational factor when it is observed that organizations or individuals will generally do that for which they are rewarded. The structure of rewards may not be designed to encourage demand recognition or the willingnes to take the risks often necessary in order to achieve utilization. Visibility of results affects motivation, because low visibility tends to reduce the level of motivation. Low visibility often affects the reward structure, because it is difficult to reward or punish behavior that is not visible (difficult to measure).

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[*] Too much competition may lower profits and the resources involved in the ability factor as indicated in Gruber's paper.

Government regulation often motivates (in some cases, even forces) organizations to respond in a given way, and this has an effect on whether there will be demand recognition and the ability/willingness to achieve the utilization of technology.

All of these facets of the motivation determinant have positive and negative values. There are interrelationships between the factors in many situations. Some examples now follow to illustrate the relationship between these four factors that affect motivation as a determinant in demand recognition and the ability/willingness to achieve technology utilization.

Wright's study of NASA's efforts to achieve commercial utilization of its advanced technology noted that efforts to achieve transfer ended in failure except in cases where top management was aware of the potential contribution from the introduction of technology developed by NASA. Wright's report of this critical determinant of technical transfer is in harmony with the hypothesis of the importance of motivation in the introduction or adoption of new technology

The speed of introduction of new generations of computer equipment has been largely a function of competitive pressure. An announcement by one manufacturer of a new capability has been followed very rapidly by the introduction of computers with an advanced technological capability by the other computer manufacturers.

If IBM, the largest computer manufacturer, had technology that was far superior to its competition, it is probable that there would be reluctance to push the utilization of this technology to the point where competition was forced out of business.

Fear of government antitrust action would thus act as a deterrent to the willingness to achieve the full utilization of technology.

Government regulation may act as a positive force. If, for example, car buyers are not motivated to pay for safety or air pollution features, then competition will not serve to force automobile manufacturers to introduce the technology to solve these problems. The reward system in business is measured in profits and not in contribution to some intangible public welfare. Government legislation is now forcing automobile manufacturers to install safety and air pollution equipment (a transfer of technology from inventory to utilization) despite the fact that the automobile manufacturers and their customers have expressed little interest in the problems that the safety and pollution control regulations were legislated to correct.

In this example there was not an absence of technical feasibilit recognition. Until the government regulation the automobile manufacturers quite correctly perceived that there was not a demand (i.e., a willingness to pay for the safety and pollution control devices). Only when the definition of demand is expanded to include the values expressed by the collective power of government can it be said that the automobile manufacturers failed in demand recognition.

All four motivational factors in demand recognition and the ability/willingness to transfer technology can be seen in this example of auto safety and air pollution. Competition did not motivate; the reward system would have penalized (in decreased profits) the innovators of safety and air pollution devices;

the visibility of poor performance (the link between air pollution and automobiles) was low; and the government had shown little inclination to regulate safety and air pollution. All forces led to low motivation, and little transfer of technology for safety and air pollution control occurred until government regulation was initiated.

If there is, in fact, no demand for action, then there cannot be a failure of demand recognition. There may be an expressed need, but this is a value judgment. Some people feel that there is a disparity between an actual and a preferred state. The concept of demand requires that there be a market for an innovation and that this market (demand) be large enough and at a price high enough to warrent action by a supplier of the invention or innovation.

Motivation for demand recognition or for ability/willingness to transfer technology into utilization becomes a human factor problem rather than an economic factor question when myopia results from a failure of motivation.* If there is an absence of competition, for example, as in the steel situation**, and this leads to low motivation for technological change with serious adverse consequences, then the failure of motivation results in behavior that can be understood within the human factor. In fact, motivational factors

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* It enters the domain of human factor if the value system of individual vs. public welfare is raised. If an individual (or a corporation) harms the public welfare but is not motivated by the reward structure or other facets of the motivation determinant, this could be rational action from an individual (or corporate) perspective.

** See M. A. Adelman, "Steel, Administered Prices, and Inflation," Quarterly Journal of Economics, Vol. 75 (1961) for an extended discussion of the failure of competition in this industry.

such as the uncontrollable force of competition (or its absence) are perhaps one of the most important determinants of the recognition and the ability/willingness essential to achieve technology utilization.

Schon observed at the MIT conference that "the mere existence of a lot of technical information, data, or technology is no reason _per se_ for spending money to get it used." He asked, "Do you concentrate on transferring technology that already exists, or do you concentrate on working with problems that seem to require technological innovation?" The answers to Schon's questions can be found in the human factors in the transfer process. Mission orientation and the motivation to innovate appear to be the key determinants of transfer, not the availability or an inventory of technical information.

A similar reaction to the MIT conference papers was given by Menzel who observed, "Perhaps the more crucial question is not so much, 'Is there some existing information that could help me to perform my tasks?' as it is, 'Should I perhaps take on new tasks in view of information that exists somewhere?'"

THE SCIENCE-TECHNOLOGY RELATIONSHIP

There has been discussion and debate about how science becomes embodied in advanced technology.* Some believe that science is quickly applied into technology in a science-leads-to-technological-advance sequence. Others

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* See, for example, Brooks, (1967), Toulmin (1966), Sherwin and Isenson (1967) and letters in response to Sherwin and Isenson in _Science_ (1967, pp. 397-398), Weinberg (1966), Price (1967), Brode (1964), Reiss and Balderston (1966), Allison (1967).

believe that the advance of science is a phenomenon quite independent of technology, and that science progresses at a rate that is a function of its past rate of advance. Still another opinion is that science is a good in itself that should be supported for the sake of knowledge, and that its relationship to technology is a fringe benefit that need not enter into the calculation of the value derived from scientific effort.

The wide diversity of opinion on this question may be narrowed through an application of the findings reported in this volume. First, there is an inevitable and considerable lag of time between scientific discovery and technological utilization. This lag was indicated in Isenson's paper. Schmookler (1966) also indicated that technological advanced in his sample were not based upon recent science.

The science-to-technological-advance sequence may have an interesting twist. A relatively rapid transfer of science into technology may tend to be related to gap filling in cases where technology has advanced ahead of science and the missing science is specified by a technological problem (Marquis and Allen, 1967, pp. 1058-59). Mission orientation can thus speed the transfer of science into utilization.

Reiss and Isenson reported little application of recent science emanating from academic institutions except in situations where a firm had a basic science group working on a similar problem and were able to contribute to the transfer from science to technology through the resources of the industrial base within which they worked.

McClelland observed that scientists were rewarded by publication and did not see the implementation of their discoveries (the transfer from science into utilization) as basic to their function. This observation, although at first reading it might seem in conflict with the findings of Reiss, is entirely in harmony with experience. There apparently exists a difference in motivation between a scientist working in industry and a scientist working in an academic institution. McClelland's findings appear relevant for scientists in the academic establishment. Reiss also expressed reservations about the values and the experience of the academic scientists who, as Goldman (1967, p. 96) noted, "publish(ed) in a narrow field of specialization in the journals dedicated to their fields."

The lack of motivation for demand recognition may explain the difference between academic and industrial scientists. The academic community ("viewed from the sheltered cloisters of academe") was blamed by the reviewer of a recent book of readings on urban problems (Entevistle, 1967, p. 1) for the low quality of solutions offered by social scientists publishing in this field.

This observed failure of academic social scientists is an example of mistaken expectations. Mission-oriented organizations have a need for scientists, personnel trained at the frontier of a discipline. This training provides a capability that is useful for solving technological problems even in situations in which the actual science used is not "recent" in terms of discovery date.

The contribution of academic scientific research* is the training of students who are then able to engage in applied projects. Solow (1963, p. 8) indicated this for science in economics:

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* An exception here is the large applied projects that are often as mission oriented as development projects in industry.

> I like a man to have mastered the fancy theory before I trust him with the simple theory. The practical utility of economics comes not primarily from its high-powered frontier, but from fairly low-powered reasoning (I think this occurs not for any intrinsic reason, but because the data are not available to give precision to high-powered theory. And in addition, it often turns out that the high-powered theory of today is the low-powered theory of tomorrow). But the moral is not that we can dispense with high-powered economics, if only because high-powered economics seems to be such an excellent school for the skillful use of low-powered economics.

Solow's observation aptly describes the relationship between academic research and the transfer of science to technology The actual transfer of science into technology requires a significant lag, but the training of scientists who then enter into applied projects makes an immediate contribution to the advance of technology.

"Professionalism" is a concept that should be contrasted to mission-oriented activity in an analysis of the science-technology relationship. Academic scientists do not have specified mission except the pursuit of knowledge for its own sake. The evaluation system and reward structure in the academic community are based upon scientific competence as observed by one's peers in the academic community. Usefulness to the outside world does not necessarily enter into this system. Until very recently attempts to estimate the effect on the quality of teaching of this reward system were given little attention Professors provide an example, therefore, of professionals who are not subject to mission-oriented motivation to work toward the transfer from science to utilization of technology.

There is even some concern as to whether interest in the application of knowledge is in harmony with the pursuit of knowledge. Many universities limit the amount of consulting that may be done by professors.

If it is accepted that the two contributions of academic research are: (1) to provide personnel trained at the frontier of knowledge who are able to use this training in applied projects in industry, and (2) advance the state of science for some future application to technology, then there should not be concern over the findings that have reported the low contribution of recent science of technological utilization.

The translation of national technological requirements to the academic community occurs when the profile of funding for academic research reflects technological problems. The funding for academic research produces scientists who are able to contribute to the technological problems. This process through which government funding produces scientists trained in the disciplines found to be essential for technological requirements was described in the paper of William Price and his associates in AFOSR. Given this understanding of the contribution that should be expected from academic research, then it is entirely rational for a mission-oriented agency to fund academic (non-mission-oriented) research. The value of such funding should not be measured in terms of science that finds rapid incorporation into mission objectives. Instead, the first returns to the mission-oriented organization are in personnel trained in the disciplines found necessary for applied work. Only when a longer time span is considered should contributions of science into technology be expected.

This focus on the science-technology relationship may be summarized as follows:

(1) The immediate contribution of science to technology is in the training of personnel to be employed in applied projects.

(2) The longer run contribution occurs after a necessary lag between discovery and utilization has occurred.

(3) In cases where technology discovered a science gap and needed science is specified, then there may be relatively rapid transfer from science into technology under the spur of mission-oriented organization.

This application of the research findings on the transfer of science to technology indicates the usefulness of such research. In a field heretofore dominated by opinion, the basis for an operational understanding of the process of transfer has been reached.

NEED FOR FURTHER RESEARCH

A comparison of the information specified by the structure created in Figure 3 and the findings that were available for review indicates that most of the necessary research has not yet been done.

An understanding of the human factor in the transfer of technology, based upon rigorous scientific investigation, represents a gap in the state of managerial technology. A review of the factors cited by Burns to explain the industrialization of Great Britain indicates the complexity of the impact of society on technical progress at a national level.* Burns noted, the development of the institutions that facilitated technical progress began in Britain about one hundred years before France and Germany achieved the market economy, and the resulting motivations permitted Britain to initiate what is now called the Industrial Revolution.

That the process of technical advance is one that required conditions that do not necessarily remain constant over time can be readily observed. How can the speed of technology transfer to Japan and its efficient utilization there be explained? Why has Great Britain lost this capability? What happened over time to alter the steel industry from one in which technology was eagerly sought to one in which adoption of new technology was slow

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* See Wolff, H., "The Impact of Society on Science," The American Behavioral Scientist, May 1967, for a further discussion at this level of analysis.

The complexity of such questions indicates that a process methodology will be needed. Different weights for the variables would be expected at the various levels of activity (as specified in Figure 3). Demand recognition, technical feasibility recognition, inventive activity, ability/willingness to achieve utilization are all parts of a systems analysis of technology transfer. After parts of the system are understood, it should be possible to link findings together into a more complete model of technology transfer.

It is interesting that scientists and engineers, people trained to seek feedback and insist upon empirical evidence, have been content to conduct their activities without the benefit of research on the process of technical advance. Folklore on research management is passed on by men trained in a tradition that does not permit the publication of unsupported statements in their technical journals.

The great variance in performance as measured by technology transfer observed when studying nations, industries, companies, and organizations indicates this capability is one that warrants a better understanding than is currently available. A comparison of the amounts of money allocated to advance technical knowledge or to assist developing countries or regions with the amounts allocated for research on the process through which new technology is utilized indicates a disparity that would be corrected if a cost/benefit analysis were to be applied, and the results of this analysis implemented.

Given the value of the existing inventory of technical information and the findings reported that: (1) most of the needed technical information exists in inventory at the time of demand recognition; (2) if there is this variance in the efficiency with which technical information is transferred, then the returns to research designed to increase the understanding of the process of technology transfer have a high expected value. A reduction in the observed variance and some control over the process in order to increase the overall efficiency of transfer both appear to be possible.

There is a difference between need and demand for a new technical capability. In this volume the need for the advance in understanding of the technology transfer process has been identified. When demand recognition for the required advance in managerial technology (i.e., the better understanding of the technology transfer process) is specified, it is probable that it will be discovered that the necessary technology needed to satisfy this demand will be found with relative ease in the available inventory.

Perhaps the best testimony for the knowledge gained in the MIT Conference on the Human Factor in the Transfer of Technology is the detetermination that demand recognition for a better understanding of the transfer of technology will be solved in part by a transfer of technology from the available inventory in the sequence of activity outlined in this chapter.

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