THE TRANSFER OF MANUFACTURING TECHNOLOGY FROM UNIVERSITIES TO INDUSTRY IN THE UNITED STATES

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SUMMARY

In attempting to bring order to a somewhat vague concept of technology transfer, within the context of universities transferring manufacturing technology to industry in the United States, I have discussed some of the relevant literature in terms of the elements of TT and the industrial innovation process.

The subject of the transfer of manufacturing technology from universities to industry in the United States is broad and diffuse. Although there are examples of specific such programs which have existed for some time in the United States, the majority have been established only recently. They have taken many forms and have had varied levels of achievement.

In attempting to bring some order to this subject, I will first present some concepts and models which I have found useful in approaching "technology transfer" (TT). Subsequently I will discuss the literature I have reviewed on the subject of manufacturing TT from universities to industry in the United States within the structure of these concepts and models. The term "technology transfer" has come to mean many things to different people, and it is advisable to define the context within which the subject of this paper is addressed.

Since 1973, I have found it useful to think about TT in terms of "elements" -- i.e. Source, Receiver, Technology, Linking Mechanism, Source Environment, Receiver Environment, and a Greater Environment -- See Figure 1. This is a simple, static way of looking at TT, but it helps to begin organizing one's thinking on the subject.

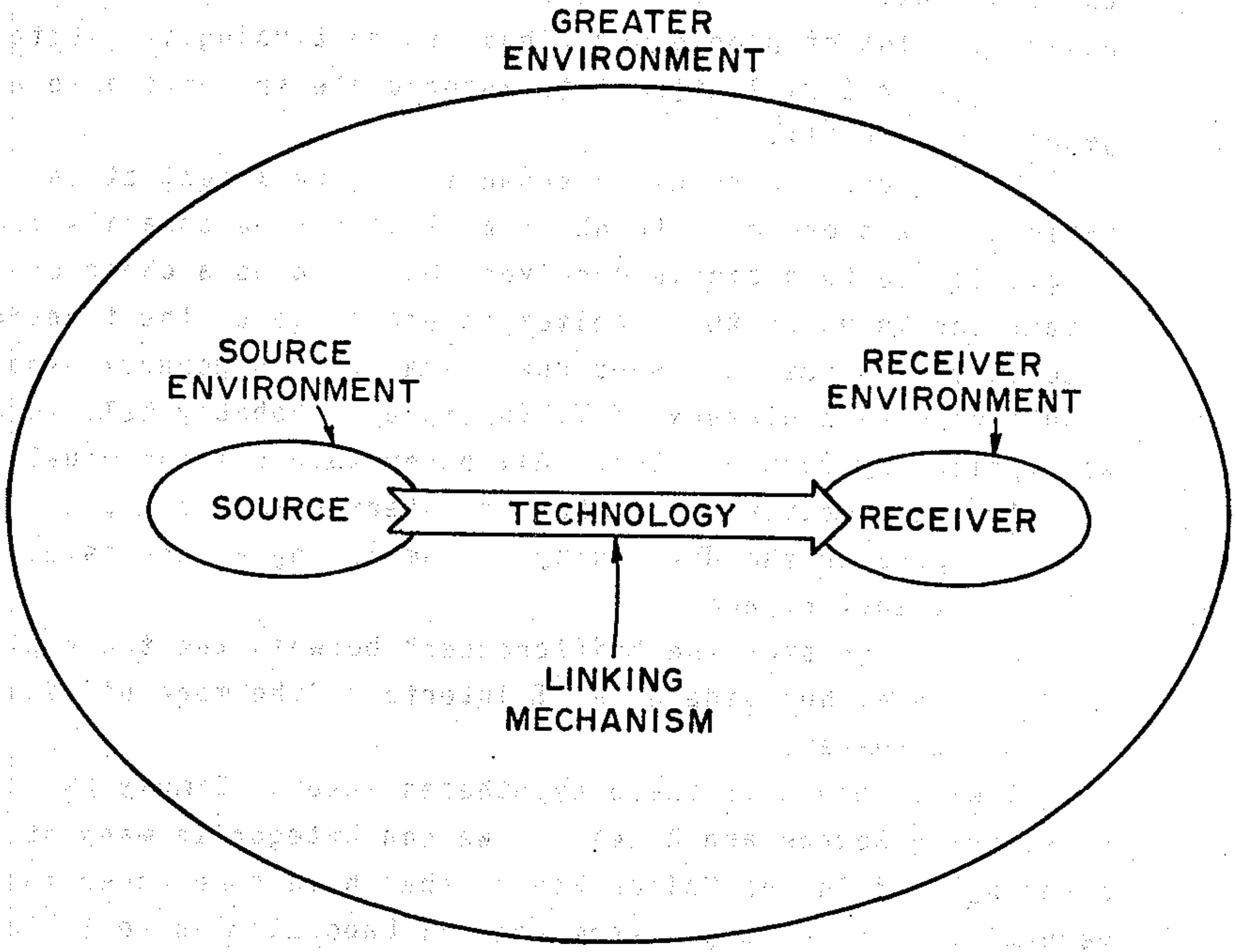

Figure 1 - Elements of Technology Transfer

Technology transfer implies the movement of technology from one entity to another, and, if the transfer is successful, the understanding and use of the technology by the receiving entity. (In other words, if the receiver does not understand and use the technology, the transfer is incomplete.) Because this movement of technology has direction, the entities are labeled Source and Receiver. Different people want to focus on different levels of Source and Receiver -- i.e., individual to individual, organization to organization, nation to nation -- but the use of the term entity includes all levels. Ultimately, of course, when behavioral aspects of the transaction -- the conditions of the technology movement -- are examined, we must deal with individuals.

Some people -- particularly in NASA and DoD -- tend to think of TT in the spinoff sense -- i.e., the adaptation of technology from one use to another, from military or space to commercial applications. If the term TT were to be confined to spinoffs, however, a lot of people would have to quit using it. Later on in this paper I will attempt to incorporate spinoffs into a more general view of TT.

The Source and Receiver shown in Figure 1 meet at an interface, and one must think of a TT as not necessarily from a single Source to a single Receiver, but also as a chain of interfaces in which the Receiver at one stage of the transfer becomes the Source in a subsequent stage. Two general hypotheses result from this picture of TT (which are probably held to be assumptions by most people). All other things being equal:

1) The greater the number of interfaces in a TT, the greater the difficulty of completing a successful transfer; and
2) The greater the "differences" between the two entities on either side of a TT interface, the more difficult the transfer.

I will return to these hypotheses later. Simply by considering Source and Receiver, we can categorize many of the changing foci in the United States that have come under the general TT term -- e.g., from Federal Laboratories to State and Local Governments, from the United States to the developing countries, from farmer to farmer, from NASA to commercial industry, etc. In this paper, of course, we will be specifically concerned with TT from universities to industry.

The <u>Technology</u> element in Figure 1 can become very confusing in academic arguments about the real meaning of things. I try to explain "technology" in terms of the knowledge and means "to do something" -- e.g., to design and/or make a computer. The term "knowhow" often is raised in this context, but it refers more to a subset of unstated, almost instinctive knowledge of how to do something. The computer, the physical object, is the product or artifact of technology -- not the technology itself -- and therefore TT is something more than the movement of goods from one entity to another. (There is, however, technology "embedded in" products that can be obtained via reverse engineering. Therefore, products are included as one of a number of examples of the Linkage Mechanism element.)*

Some people speak of "technology" -- how to do something -- in a very general sense, and include concepts of, for example, management technology and social technology in addition to the more conventional hardware technology. They would include transferring the knowledge and means of how to motivate subordinates (management technology) or how to provide welfare assistance (social technology) in the concept of TT. I prefer to restrict the concept of technology to hardware, although there are gray areas. When the non-hardware kinds of things are included under TT, the subject begins to become too diffuse to handle. There is this relationship (or hypothesis), however: in order to successfully transfer hardware technology, management and social practices and technologies often must also be transferred.

The transfer of technology phrase in and of itself says nothing about whether the technology is new (an innovation) or existing. Nevertheless some people definitely have <u>new</u> technology in mind when speaking of TT, particularly from universities to industry, while others may include - or even emphasize - <u>existing</u> technology which still is an improvement over the technology presently used in practice. This distinction affects the other elements of the system, as will be pointed out, and is treated later in the discussion of diffusion of innovation.

In this paper we will be looking at "manufacturing" technology in the general sense - i.e., how to manufacture products in general rather than related to a specific product. Part of our problem will be to define more precisely what "manufacturing technology" is and/or includes.

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*The sale of industrial products from one entity to another can be an indicator of industrial development where the technology in question concerns how the products <u>are used</u> in industrial processes - <u>not</u> the technology of designing or manufacturing <u>the products themselves</u>. For example, increasing sales of computers could be an indicator of -- assuming they are used successfully --the development of data processing technology in the Receiver, but not the transfer of technology to design or manufacture computers. The sale of a single computer on the other hand, could involve TT in computer design and/or manufacturing if it was reverse engineered to obtain the technology embedded in the product itself.

Linkage Mechanisms are the means whereby the technology is transferred from Source to Receiver. We have already indicated that products -- in the reverse engineering sense -- are one example of such Linkage Mechanisms. Sales or movement of products in and of themselves are not TT, but manuals or instructions accompanying the products are other examples of TT Linkage Mechanisms, as is training personnel in the design, manufacture, or use of the products.

Linkage Mechanisms are essentially knowledge or information containers. Many of these containers are paper (or -- now -- electronic) in which Source and Receiver are not in face-to-face contact: manuals/instructions, blueprints, licensing agreements, video tapes, published articles or non-published documents, tech briefs, etc. Many people, however, stress the importance of face-to-face contact in all communications, including TT. Examples of face-to-face Linkage Mechanisms would include training or apprenticeship programs, personnel exchanges, visits, joint ventures, technical or management extension/assistance programs, consulting agreements, etc. The ultimate and time proven face-to-face mechanism would be to recruit technologically qualified personnel from the Source to join the Receiver and bring their technology (within legal limits) with them.

The TT "agent" is often cited as a particularly useful face-to-face contact Linkage Mechanism. Coming out of the county extension agent tradition in the U.S. agricultural TT system, the "agent" is neither Source nor Receiver, but operates in between them as a human Linkage Mechanism. Consulting engineers, architectural and design firms, and even knowledgeable salesmen also operate in a TT agent role in the private sector. A more recent private sector development has been the emergence of small, new firms whose explicit business is TT for profit, acting as an agent.

The Source Environment is the immediate set of conditions under which the Source entity is operating -- at the individual, organizational, or national level. A Source, of course, has to have technology which some Receiver wants, and in practice many people are concerned about the transfer of new technology -- i.e., from an R&D environment. The assumption that R&D organizations, particularly in universities, have technology which industrial manufacturing Receivers want, however, is open to question.

Some of the conditions that would make up the immediate environment of the Source entity might include its economic health or needs, its technological health or status, an inward vs. outward-directed orientation, its stability or instability, its commitment to TT as opposed to other activities, etc. These kinds of factors could affect the Source entity's decision to transfer its technology and its capability to implement the transfer effectively.

As the Source of technology, the Source entity is in a position of relative power over the transfer transaction decision -- a decision that will be influenced by its immediate environment. Even if it decides to transfer technology, however, it cannot do so successfully by itself -- the Receiver entity and its immediate environment must also be willing and able to complete the transaction.

The principal issue concerning the immediate <u>Receiver Environment</u> is known as "absorptive capacity" -- the ability of the Receiver to understand and use the technology. (We usually assume that the Receiver is a willing participant in the TT, but this may be true at the surface level only.) Many of the absorptive capacity factors are aspects of physical and human infrastructure. Such things as a stable electricity supply, repair and maintenance facilities, trained individuals, etc., are some of the factors often cited in discussing the difficulties in TT to developing countries, for example, but they can apply in varying degree to the immediate environment of any Receiver entity.

There are a series of Greater and Greater environments surrounding the Source and Receiver environments, depending on the level of the Source and Receiver entities we are dealing with. A couple of examples should illustrate this. TT between two firms within the United States would be carried out within a national environment which might include anti-trust policy, tax policy, macro economic performance, stock market performance, etc. TT between two nations (or firms in two nations) would be carried out within an international environment which might include East-West relations, OPEC-Middle East stability, exchange rate fluctuations, bilateral/multilateral trade negotiations, etc.

I would now like to move to another way to view TT, and will begin with a brief discussion/description of technological innovation. The upper half of Figure 2 on the following page shows a conventional stage model of the production function or supply side of the process of technological innovation. The stages in this process are well known. Basic (fundamental, pure) research is done without any practical goal or objective in mind, principally in universities, producing knowledge for its own sake. Applied research does have a practical goal or objective in mind, and the research is directed toward establishing an idea or concept in the laboratory. (Sometimes the term "mission-oriented basic research" is used to convey an intermediate stage between the above two; "generic technology" research is a relatively new term which also exists somewhere in between the basic and applied stages.) Development/engineering designs and fashions apparatus for experimenting with and testing the concept, and if successful in a laboratory demonstration, a working model prototype (product innovation) or pilot plant (process innovation) is designed and constructed to test the innovation under field conditions at a small-scale. Based on what is learned in small scale operations, the innovation is scaled up until it reaches the intended size and/or complexity of the full-scale product or production process. Marketing occurs subsequently, and in some cases follow-on services for products sold may be required.

Like all models, this one greatly simplifies a very complex process. It does not necessarily represent the process by which any specific innovation has ever resulted. In reality, stages may be absent, they may occur in different sequences, feedback loops (from marketing to applied research, for example) may be critical, etc. Nevertheless, this model does represent an orderly, rational progression through the process of technological innovation. The point to be made here is that to the extent that one stage of this process is done by different people, different parts of the organization, different organizations, different nations, etc., from the preceding or succeeding stage, a TT occurs. In this process, a change in the state of the technological development of the innovation is the result of the successful TT. This process is sometimes referred to as vertical technology transfer.

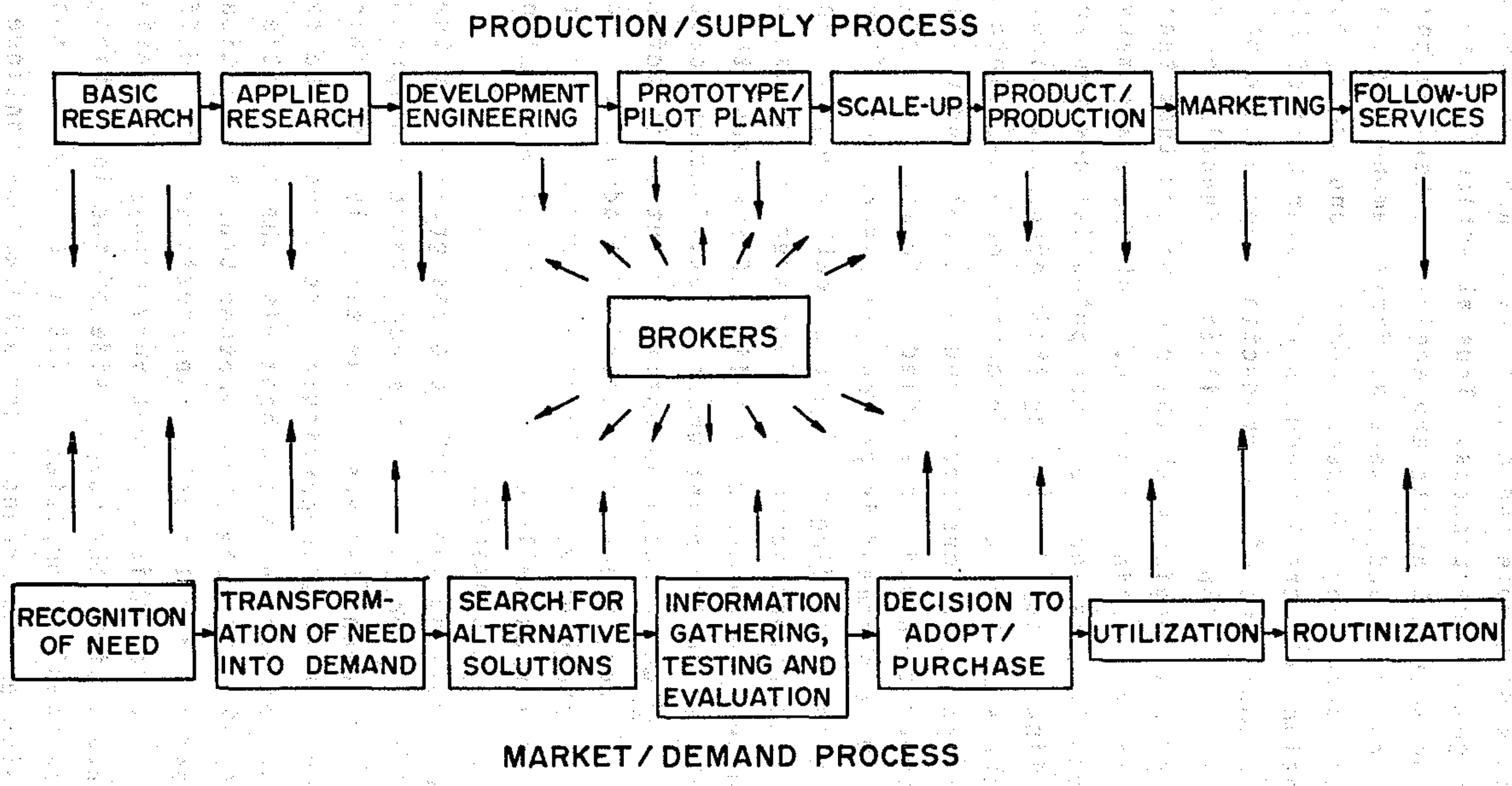

Figure 2 - The Technological Innovation Process

Vertical TT encompasses a variety of concerns about the movement of technology from research into application when different kinds of people and organizations are involved at different stages of the process. Thus attention is paid to the differences between scientists and engineers, between government research laboratories and commercial firms, among R&D and production and marketing, between producers and users, etc.

The mention of users introduces the lower half of Figure 2, which is the complement of the production/supply side of technological innovation -- the utilization function or demand side. This process begins with the recognition that there is a need, or an identification of a need. But there are many unfilled needs in this world because potential needers are unable and/or unwilling to pay for having their needs satisfied. Therefore, there must be a transformation of a need into a market demand, where potential customers would be able and willing to pay for an innovation under specified performance and price conditions. Once a demand is present, a search for alternative solutions begins, including information gathering, testing, and evaluation of different approaches, different products, different services. Depending on the criticality of the need, the search may continue only to the point where a satisfactory solution is found, or it may go on until an optimal solution is defined. At some point, however, there is a decision to adopt or purchase an innovation. Subsequently, utilization occurs and, over time, the innovation becomes assimilated into the normal and routine operations of the customer/users.

This model of the innovation process grew out of the rural sociology field and research on the acceptance and spread of hybrid seed corn among farmers in the early 1900's. This early work, by Everett Rogers in particular, resulted in the term "diffusion of innovation" and a book with the same title (ref. 1). There is some dispute about whether true "innovation" extends beyond the first adopter/user/customer, and "diffusion of innovation" finesses this argument very nicely. Diffusion occurs, however, after the supply side of the innovation process has been essentially "completed". (It is hardly ever absolutely completed --incremental changes and adaptations continue to occur, succeeding generations of technology are developed, etc.) Diffusion is technology transfer that occurs without significant change in the state of technological development of the innovation, which is sometimes referred to as horizontal TT.

Before discussing horizontal TT, I would like to finish up Figure 2 and the discussion of innovation. As shown, the two complementary models of innovation must fit together somehow for the process to be successful. How this happens in practice, however, is never as neat and ordered as Figure 2 would suggest. In particular, one should picture them as sliding and breaking up on a horizontal time scale in all manner of combinations.

For example, in the case of a radical new product innovation in which demand has to be created, the supply/production process may go all the way to the marketing stage before a recognition of need occurs and the demand/utilization process begins. At the other extreme, Eric Von Hipple has shown how the recognition of need can occur first among the users/customers of scientific instruments and the demand/utilization process continues through testing and evaluation before the producers/suppliers of instruments are approached and informed of what innovation is desired (ref. 2). Figure 2 also shows the Broker/change agent function operating between the suppliers and users of innovation.

Horizontal TT involves a concept of "distance" and is related to the earlier stated hypothesis that the more different the two entities are on either side of a TT, the more difficult the transfer. "Distance" includes geographic distance -- the farther apart spatially the Source and Receiver are, the more difficult the transfer -- but it goes beyond spatial distance to encompass differences in language, values, religion, culture, nationality, standard of living, technological sophistication, economic philosophy, political/governing systems, etc. This point is perhaps best illustrated in international terms. Canada would probably be the country "closest" to the United States for the transfer of technology, while Chad might be one of the "farthest".

These concepts of horizontal and vertical TT are shown in Figure 3 on the following page. On the vertical TT axis, an adaptation process coming out of applied research is added for spinoffs which can continue on as a separate supply/production innovation process or merge back into the original stream. I have used an international level dimension on the Horizontal TT

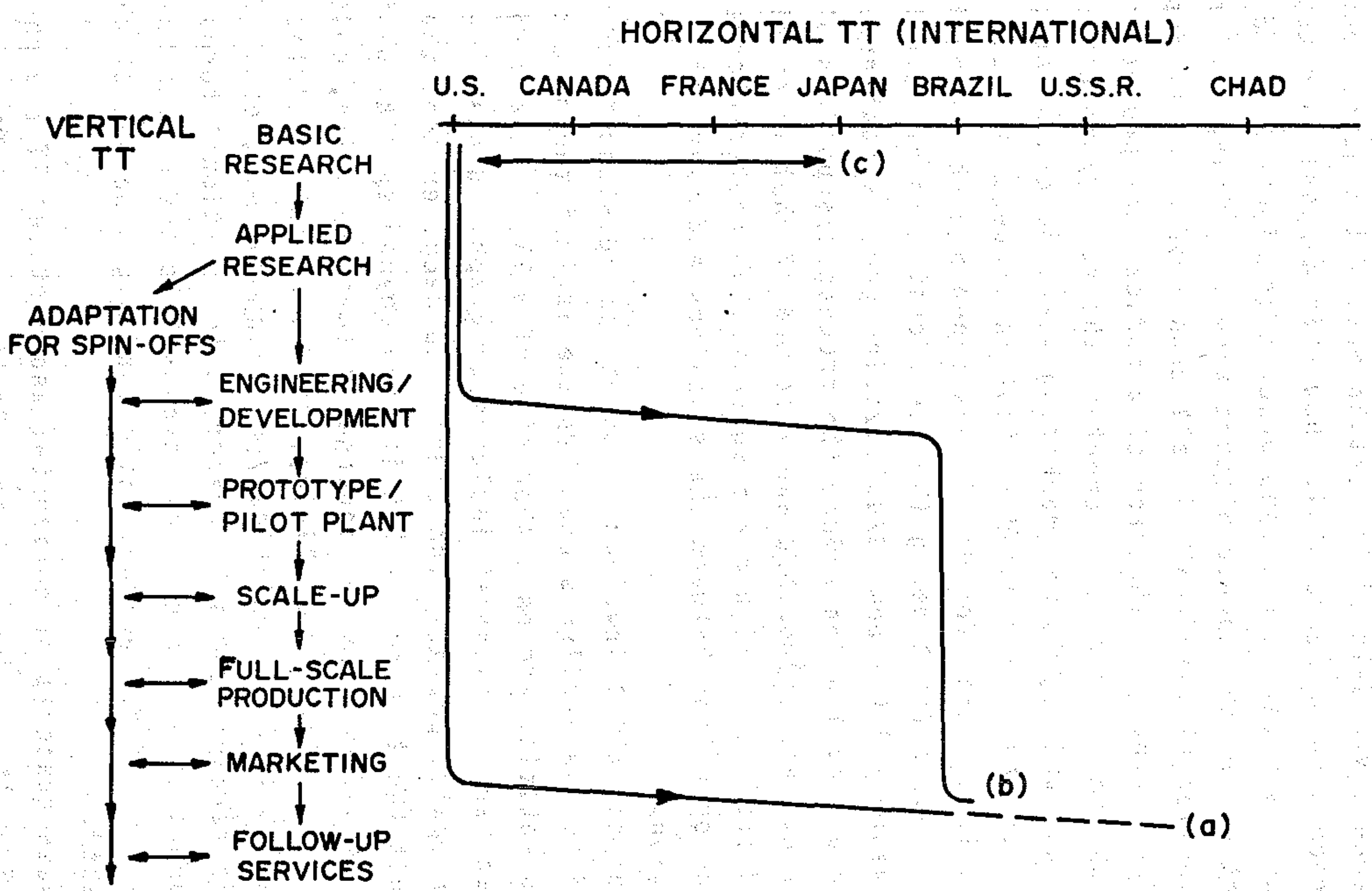

Figure 3 - Horizontal and Vertical Technology Transfer

axis, but later on in this paper I will discuss university - industry differences and TT in this context.

We can think of different kinds of TT which can be placed on this "map". An innovation which occurred entirely within the United States and then was diffused around the world might be pictured as line (a). A licensing agreement with Brazil for a technology developed but never put into practice in the United States might be pictured as line (b). A scientific exchange or cooperation agreement between the United States and Japan, with no technological or commercial purpose or outcomes might be pictured as line (c). And so on.

I shall now turn to discussing some of the issues concerning the transfer of manufacturing technology from universities to industry in the United States within the context of the above concepts and models. Before beginning, I should like to mention some assumptions that underlie this subject. In speaking of university-industry alliances, Nelkin and Nelson state that:

> They have been created for different reasons, but in every case they involve an element of faith that they will be good for business, helpful and appropriate to universities, and in the public interest. (ref. 8, p.8)

I would phrase these "elements of faith" as follows:

- That manufacturing technology development and/or application can play a significant role in addressing the problems/opportunities facing U.S. industry;
- That U.S. universities and colleges have manufacturing technology or manufacturing technology capabilities that can be usefully applied to the needs of U.S. industry; and
- That promoting relationships, interactions, alliances, cooperation etc. between U.S. universities and industry - with government funds and assistance in many cases - can establish and strengthen the TT process between them.

The literature which I reviewed on this subject appears to fall into three interrelated categories:

- university - industry cooperation in general
- university - industry cooperation in research or science
- university - industry cooperation in manufacturing

The sources of this literature are prinicipally the National Science Foundation, particularly because of its university-industry cooperative research centers program, and the National Academy of Engineering through its Manufacturing Studies Board.

Although technology transfer is not emphasized by name in the titles of the reports examined, it is addressed in all of them. Peters and Fusfeld, for example, in their study of U.S. university/industry research connections (ref. 3), discuss four types of "research interactions": general research support, cooperative research support, knowledge transfer mechanisms, and technology transfer programs.

I would like to distinguish among the following kinds of university TT activities that often are lumped together, potentially causing some confusion:

1) The technology transfer functions of university R&D activities. University R&D programs with or for industry often include a TT function as standard operating procedure. R&D TT concerns new technology, and can be both a vertical and horizontal TT occurring at any stage prior to (probably) prototype/pilot plant in the innovation process - Refer to Figure 3.
2) University technology transfer of new technology on its shelf, just waiting for the right industrial partner to recognize its value and pick it up. This would again be a vertical and horizontal tranfer, but would not be part of an active R&D operation.
3) The special case of technology transfer to assist university faculty in becoming entrepreneurs in order to exploit new technology they have developed. (Since the individual who developed the technology stays with it, this may be more of an assistance than a transfer function according to the above definitions.) Many universities and state/local governments would like to emulate the Boston Route 128 model without, of course, a significant permanent loss of critical faculty.
4) Technology transfer which seeks to apply university technological capabilities to the problems of industry -- e.g., problem-solving, consulting arrangements, technical assistance, scientific and technical information, etc. This is a horizontal transfer of existing technology. If problem solving or consulting results in an R&D or new technology project at the

university, this would revert to one of the above categories.

5) Technology transfer which seeks to act as a broker between industrial needs and any source of new or existing technology - one of these sources being the university at which the TT function is located.

6) One of the principal functions of universities and colleges is education and, more and more, training. Short term, concentrated courses/workshops and continuing education programs for graduated professionals may be viewed as TT activities.

In this paper, I will try to stay away from university - industry R&D in manufacturing areas and to focus on TT, but to some extent there will be an inevitable overlap.

In reviewing the literature, a number of surveys and studies of university - industry programs were included. These will be briefly discussed here, and referred to at various points later in the paper. In discussing the surveys and studies, I will be specifying what portion of the total programs were directed specifically toward manufacturing or were manufacturing related. Because descriptions are sparse and interpretations are limited in some cases, the numbers can only be approximate and are conservative.

The National Science Board of the National Science Foundation published selected studies of University-Industry Research Relationships in 1982. The principal study in this volume was by Lois Peters and Herbert Fusfeld of the Center for Science and Technology Policy at New York University (ref. 3). They visited 39 universities, about 60-65 companies, and a few other organizations, which formed the basis for their sample of university - industry programs. The university sample included private and public institutions, but concentrated on the top 50 research universities (12 universities below the top 50 were included, but all were within the top 200). The companies visited and technical fields included covered a range of industries and disciplines, but the companies tended to be large, with R&D budgets over $100 million. Although this study focused on research connections, as indicated earlier "knowledge transfer mechanisms" and "technology transfer programs" were included as two of the four types of research interactions.

A total of 473 university programs with or for industry were identified by Peters and Fusfeld, although there is some redundancy in their list. Of the total, 18 clearly and directly dealt with manufacturing - 11 in a general way (CAD-CAM, Robotics, manufacturing productivity, etc.), three specifically with metal forming and cutting, one with chemical processing, one with biotech fermentation, and one with computer manufacturing. An additional 16 were related to or partially concerned with manufacturing processes or functions - e.g. catalysis, surfaces and coatings, powder metallurgy, welding, etc.

University/Industry cooperative research centers, located at U.S. universities, have been sponsored by the National Science Foundation (NSF) since the early 1970s. The NSF has documented the development of these centers and how they have worked in two editions of "historical profiles" (ref. 4). Technology transfer is included as a function of these R&D operations.

Of the seven centers discribed in the first edition, none were directly and clearly focused on manufacturing, but at least two are manufacturing related - the Center for Welding Research at Ohio State University and the Center for Ceramics Research at Rutgers University. In the second edition two general manufacturing centers are added - the Robotics Research Center at the University of Rhode Island and the Material Handling Research Center at Georgia Tech.

In 1983, the U.S. General Accounting Office (GAO) published a study on "The Federal Role in Fostering University - Industry Cooperation" (ref. 5). It did so because of increasing Congressional interest in fostering closer links between university and industrial institutions in order to improve national technological and economic performance. GAO selected three types of university - industry collaboration to study: research parks (three cases); cooperative research centers (nine cases); and industrial extension services (four cases) -- 16 cases in total. Four of these cases were the subject of in depth studies; the remainder were not studied in as great detail.

Of the 16 cases in this sample, only two dealt directly and clearly with manufacturing - one in the general sense and the other with polymer processing. An additional four cases were related to manufacturing in fields such as catalysis, welding, and pulp and paper production. The four cases of industrial extension services directly involve technology transfer, but are not focused on manufacturing.

In 1984, the NSF took a different look at their industry/ university cooperative research program by examining projects and researchers (ref. (6). Nine cooperative research projects were identified and issues related to project management and coordination and communication among university and industry researchers were studied.

Of the nine projects, none clearly and directly dealt with manufacturing. Three of the nine, however, were related to manufacturing - in filtration processes, electro chemistry, and non-destructive testing.

In 1984, Dr. Helen Haller of Cornell University published survey data on 157 programs of U.S. university - industry collaboration (ref. 7). Almost all of the programs have some R&D component, but other functions/activities are also present and included.

Data for each program (in addition to basic names, addresses, etc.) include the founding date, a categorization of the programs, participants, sources of funds, and the science or technology involved. Fourteen non-exclusive categories of programs were identified, with a 15th category provided for programs in the process of forming. Any program could fall into a maximum of four categories. The categories and number of programs in each are listed below.

Consortia of Universities[1]	24
Donors of Research Grants	29
Incubators	11
Industrial Affiliates Programs[2]	39
Industrial Cooperatives[3]	10
Industrial Extension Services	18
Long-Term Research Partnerships and Agreements[4]	20
Non Profit Corporations and Organizations	34
Research Parks	15
Small Business Development Centers	11
State Government-Established Centers/Programs	46
University Affiliated Foundations	4
University-Industry Cooperative Research Centers	15
Programs Aiding with Access to Venture Capital	13
Programs in the process of Forming	15

1) Any program in which two or more universities participate.

2) Arrangements in which a number of companies in the same field or with similar research interests all contribute membership fees to a university program.

3) Any program in which two or more companies participate, other than as industrial affiliates.

4) Usually involve a contract for research funding for a number of years, rather than a relationship that happens to last, excluding industrial affiliates.

This categorization scheme is multi-dimensional and so can be confusing. All of the programs would fit into one or more of the six categories of university-industry TT defined earlier in this paper. Other than the linkage mechanisms identified in this list, one should note the large number - 46 - of state government established centers or programs - a point that will be mentioned later. In Haller's report these categories and the programs themselves are grouped by source of funding - i.e., corporate sponsors; gifts, contributions, private funds; fees - for services, courses, computer time, data; government - Federal/State/Local; industrial affiliates membership fees; investment/endowment income, royalties; membership fees; grants or contracts; rents or leases; university support; venture capital; and specified matching funds. Programs may have more than one source of funds, of course, and interpreting the data is difficult because the relative importance of different funding sources is not known.

An examination of the "science or technology practiced" information listed for each program, showed that 12 out of the 157 programs dealt clearly and directly with manufacturing -- 7 with manufacturing in general, and one each for biotech fermentation, materials handling, chemical processes, and ceramics. A further 12 programs were related to manufacturing.

As part of the background work which they carried out for the National Academy of Sciences/Engineering, Nelkin and Nelson reported on 21 university-industry programs which they visited or about which they received information (ref. 8). These tended to be major initiatives that have received much attention.

Of the 21 programs, 5 were clearly and directly involved in manufacturing - one in general manufacturing, and the others in durable goods, electronics, biotech, and iron/steel manufacturing. An additional 5 were in manufacturing related areas. The largest number of programs -- 7 -- concerned product/systems development, and the remaining four were in small business/entrepreneurship fields. Nelkin and Nelson cluster these programs in the following way:

- Research programs or centers that support many research projects and that are closely tied to general academic research and teaching activities.
- Focused projects involving both a well-defined practical objective and intellectual goals.
- Programs developed to help commercialize faculty research.
- Programs or institutions organized to help clients, operating outside the university.
- Free standing research institutes, linked to several universities (ref. 8, pp. 12-14).

No reports are yet available on the most recent program to foster university - industry linkages in the United States - the National Science Foundation's Engineering Research Centers program. Six centers were established at U.S. universities in 1985, and five more in 1986. The purpose of the program is as follows:

> The goal of the Centers program is to develop fundamental knowledge in engineering fields that will enhance the international competitiveness of U.S. industry and prepare engineers to contribute through better engineering practice (ref. 9).

The centers are to conduct multidisciplinary research on fundamental engineering problems, and to incorporate this research into their educational programs. The participation of industry and industry people in these centers is regarded as essential.

Although the Centers are oriented toward research and education, one of the features a center is "expected to possess" includes:

> Develop new methods for the timely and successful transfer of knowledge to industrial users and, as appropriate, codification of new knowledge generated at the Center and continuing education of practicing engineers. (ref. 9)

Of the eleven centers so far established, four deal directly with manufacturing: the Robotics in Microelectronics Center at the University of California at Santa Barbara; the Composites Manufacturing Center at the University of Delaware and Rutgers University; the Intelligent Manufacturing Systems Center at Purdue University; and the Center for Net Shape Manufacturing at Ohio State University. One further center is related to manufacturing in the process sense - the Biotechnology Process Engineering Center at MIT.

Finally, in 1984 the Society of Manufacturing Engineers (SME) published a directory of manufacturing education programs based on a survey which was sponsored by the SME Education Department. (ref. 10) The initial survey carried little data or information relevant to TT, but a more recent survey has just been completed which, according to the SME people responsible for it, includes information on manufacturing activities beyond formal education. Unfortunately, this data is not yet available.

One point on which all of the studies would agree - the number and diversity of university - industry programs in the United States has been rapidly increasing. Evidence for this view with respect to research interactions in shown in the Table 1 below (ref. 3, p. 22). Some of the reasons for this are discussed later in the paper.

TABLE 1

Numbers of University/Industry Research Interactions Existing for Various Time Periods

	Time Periods (Years)				
Types of Interactions	<3	3-5	6-10	11-20	>20
All Categories of Interactions	236	80	80	37	49
• General Research Support	35	11	3	1	2
• U/I Cooperative Research	149	7	37	17	18
• Knowledge Transfer	31	10	5	3	7
• Technology Transfer	21	3	10	11	21
U/I Cooperative Research Programs (Selected Categories)					
• Special Interest Liaison Programs	48	14	6	12	4
• U/I Cooperative Research Centers & Institutes	21	11	14	14	8
• Research Consortia	7	2	3	3	1
General Purpose Industrial Programs	4		1		3

Turning now to the elements of <u>Source</u> and <u>Source Environment</u>, Nelkin and Nelson appear to divide the relevant university universe into three categories:

- east coast, Ivy League universities, orginally designed to educate clergymen and the intellectual elite in the United States;
- state land grant and agricultural/mechanical arts/mining universities which were established for more utilitarian purposes; and
- technical and engineering oriented universities, mainly

private institutions - e.g. MIT, Cal Tech, RPI, IIT, etc. (ref. 8, pp. 3 & 4)

This is the same set of universities that Peters and Fusfeld were concerned with - the major research universities.

The principal purpose of this breakdown is to differentiate the "culture" of universities along a theoretical - practical scale, with those who value knowledge for its own sake and emphasize basic science at one end and those who value technology for its practical uses and emphasize the professions at the other. As Nelkin and Nelson point out, however, there is a significant variation among scientific fields and professions regarding their ability to produce practical applications which cuts across all universities. Thackary describes the historical evolution of close relationships between universities and industry in chemistry, for example (ref. 11), and current experience in the biotechnolgy field would suggest that even the most elite universities can and will interact with industry in this field.

Darknell and Darknell would add another caterogy of higher education institutions to the list of technology sources - the second tier of state colleges and universities which are not major research universities (ref. 12). Although the science and research base at these second tier institutions is not as great perhaps as at the major universities, Darknell and Darknell found that a still considerable amount of R&D and faculty consulting does take place and that a "sizeable portion" is linked to industry. Moreover, state colleges appear to have more ties to their local communities/regions and tend to stress more the idea of community service.

Darknell and Darknell cite a number of inventions and innovations that came out of the California State College system and were successfully transferred to and commercialized by industry. They use the case of the prosthetic heart valve, developed during the 1960's at Sacramento State College, as a model of how the R&D - TT process can work in universities.

I would add one further category of higher education institutions to our list of sources - the community colleges. Although community colleges may not have much R&D going on to transfer, their ties to the local community - particularly to small business - are often very strong. TT to upgrade current practice, even if not near the state-of-the-art, is often carried out successfully by community colleges, as is very practical and useful training in the latest manufacturing technologies and how to use them (e.g. repair and maintenance of robots).

The literature which specifically addresses manufacturing refers consistently to a general lack of manufacturing education, capabilities, and interest in U.S. universities. There are important exceptions, of course, but as Joseph Shea states in an Academy of Engineering publication,

> Today perhaps 5 percent of engineering schools stress manufacturing, but the problem is critical enough that probably 95 percent should be offering competent programs. It must be cautioned, however, that the <u>assumption</u>, that universities can effectively contribute to either short- or long-term improvements in manufacturing is an intellectual <u>act of faith</u>. (ref. 13, p. 20, emphasis added)

In the same publication, Forrest Brummett has published a table from the American Association of Engineering Societies showing the number of engineering degrees granted - according to engineering field - by U.S. colleges and universities in 1973 and 1983 - See Table 2 on following page. (ref. 14, p.35) The number of degrees in industrial/manufacturing engineering awarded in 1983 was the lowest of all fields (others being electrical/electronic, mechanical, civil, and chemical engineering) at bachelors, masters, and PhD levels. Morever, the rate of change from 1973 to 1983 in industrial/manufacturing engineering degrees awarded was disappointing. At the Bachelors level, there was an increase of 31%, lowest of all the rates shown, but at the Masters level there was a <u>decrease</u> of 22% and at the PhD level a <u>decrease</u> of 20%! Brummett adds that compared to the roughly 1.4 million practicing engineers in the United States today, only about 2,850 degree holding manufacturing engineers are primarily engaged in discrete parts manufacturing. (ref. 14, p. 36)

The lack of university programs in manufacturing engineering is also shown by the relatively few number of accredited programs in the field. Brummett shows a table of programs in manufacturing engineering and technology approved by the Accreditation Board of Engineering and Technology as of September 1984 - See Table 3 on following page. (ref. 14, p. 37) In addition to the few number of schools represented - 21 - one should note the predominance of smaller, second-tier colleges/

TABLE 2

Engineering Degrees Granted by American Colleges and Universities, 1973 and 1983

	1973	1983	Percentage of Change
Bachelor's degree(thousands)			
Electrical/electronic	11.8	18.6	+58
Mechanical	8.4	16.5	+96
Civil	7.7	10.5	+36
Chemical	3.6	7.5	+108
Industrial/manufacturing	2.9	3.8	+31
All other	9.0	15.6	+73
Total	43.4	72.5	+67
Master's degree(thousands)			
Electrical/electronic	4.2	4.6	+7
Mechanical	2.8	3.0	+7
Civil	2.2	3.3	+50
Chemical	1.0	1.5	+50
Industrial/manufacturing	1.8	1.4	-22
All other	5.2	5.9	+12
Total	17.2	19.7	+14
Doctorate or Engineer degree			
Electrical/electronic	820	628	-24
Mechanical	435	422	-3
Civil	411	436	+6
Chemical	405	388	-4
Industrial/manufacturing	147	118	-20
All other	1,369	1,267	-12
Total	3,587	3,259	-9

TABLE 3

Accredited Programs in Manufacturing Engineering and Technology for Year Ending September 1984, Accreditation Board of Engineering and Technology (ABET)

Study Area	Accredited Programs
Engineering	
Manufacturing engineering	Master's degree
	University of Massachusetts (Amherst)
	Bachelor's degree
	Boston University (Boston, Mass.)
	Utah State University (Logan, option in mechanical engineering)
Engineering technology	
Manufacturing engineering technology	Bachelor's degree
	Arizona State University (Tempe)
	East Tennessee State University (Johnson City)
	Milwaukee School of Engineering (Milwaukee, Wis.)
	Murray State University (Murray, Ky.)
	New Jersey Institute of Technology (Newark)
	Oklahoma State University (Stillwater)
	Pittsburgh State University (Pittsburgh, Pa.)
	Rochester Institute of Technology (Rochester, N.Y.)
	University of Nebraska at Omaha*
	Weber State College (Ogden, Utah)
	Wichita State University (Wichita, Kans.)
Manufacturing processes	California Polytechnic State University (San Luis Obispo, Calif.)
Manufacturing technology	Bradley University (Peoria, Ill.)(mechanical design or operations option)
	Brigham Young University (Provo, Utah)
	Indiana-Purdue at Fort Wayne (option in mechanical engineering)
	Memphis State University (Memphis, Tenn.)
	University of Houston (Houston, Tex.)
Manufacturing engineering technology	Associate degree
	Central Piedmont Community College (Charlotte, N.C.)
	Forsyth Technical Institute (Winston-Salem, N.C.)
	Hartford State Technical College (Hartford, Conn.)
	Ricks College (Rexburg, Idaho)
	Thames Valley State Technical College (Norwich, Conn.)
	University of Nebraska at Omaha*
	Waterbury State Technical College (Waterbury, Conn.)

* Both associate and bachelor's degrees are ABET-accredited.

universities and technical/engineering schools.

The manufacturing field is considered by many to be a combination of engineering technology and business/management skills. The business/management schools of U.S. universities have exhibited the same general lack of manufacturing operations management education, capabilities, and interests that has characterized the engineering schools. Again, there are important exceptions. A recent article in <u>Managing Automation</u> cites business schools of the Big Ten universities, Carnegie Mellon, Columbia, Harvard, MIT, and Stanford as places where manufacturing is getting "serious attention". (ref. 15, p. 46) The Illinois Institute of Technology is also in that category.

This lack of manufacturing programs was not always true of U.S. universities. Eugene Merchant says that U.S. universities and colleges had "strong programs of manufacturing-oriented engineering education and research" up until the 1940's (ref. 16).

Marvin DeVries, Director of Manufacturing Systems Engineering at the University of Wisconsin and 1985-86 President of SME, cites a number of past studies of engineering education (the Hammond Study, the Grinter Study, the ASEE Goals Study) as one of the culprits:

> Many engineering schools responded to these studies and other pressures by developing curricula having a strong science orientation with the result that engineering design and manufacturing courses and programs were virtually eliminated. (ref. 17, p.1)

He goes on to identify several reasons why manufacturing engineering is a neglected area in U.S. universities:

- The emphasis in the teaching of engineering on scientific aspects at the expense of practical aspects; a trend accelerated during the decade of the 1960's.
- Incorrect approaches in the teaching of manufacturing engineering, e.g., a purely descriptive instead of a balanced analytical/practical engineering approach.
- The late recognition of the extreme complexity and variability of many manufacturing processes.
- The pittance of federal government research support for manufacturing oriented research.
- The lack of sufficient industrial support for research in manufacturing engineering. (ref. 18, p.2)

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Another reason often cited for the lack of manufacturing programs in U.S. universities is the existing departmental/ discipline system along which lines universities are traditionally and bureaucratically organized. In the past, most manufacturing engineers have been educated in either mechanical or industrial engineering departments, along with core courses in other departments. Today, however, if one thing is agreed on, it is that manufacturing is an interdisciplinary subject which also includes important elements of electronics/computers/information science, materials science, and - as indicated earlier - business management, and that it has to be taught with a systems approach. DeVries and Koves state that the following university departments may participate in manufacturing systems engineering programs:

- Electrical Engineering
- Engineering Mechanics
- Chemical Engineering
- Metallurgical Engineering
- Systems Engineering
- Welding Engineering
- Operations Research
- Computer Engineering/Science
- Aeronautical/Aerospace Engineering
- Business
- Finance
- Mechanical Engineering
- Industrial Engineering
- Materials Engineering/Science
- Control Engineering
- Civil Engineering
- Engineering Science
- Engineering/Business Management
- Information Engineering/Science
- Mining/Mineral Engineering
- Commerce
- Marketing

Another thing that is agreed on is that U.S. universities are changing, along with everyone else, in response to the national decline in manufacturing competitiveness. Corporations such as IBM have made large investments in manufacturing programs at U.S. universities, and professional societies like SME and the U.S. Government are doing likewise. According to observers, however, universities, although they want to respond, have been uncertain about how to go about it (ref. 19, p. 2), and so a great deal of diversity and experimentation exists. DeVries, for example, says that university manufacturing systems engineering programs fall into one of three basic types:

- A Master of Science in Manufacturing Systems Engineering (MSMSE) degree offered by a new MSE organization within an established college of engineering.
- A Master's degree in a traditional discipline (i.e. Mechanical or Industrial Engineering) with an option in MSE awarded by one or more of the established engineering departments.
- A Master of MSE degree awarded by one of the established engineering departments participating in the program. (ref. 18, pp. 5-6)

(Note the assumption, held by most observers, that manufacturing engineering is a Masters degree level program.) The last two approaches are more common, he says, because they require less change in the established organization and administrative procedures of the university.

Although the preceding discussion has centered on the educational aspects of manufacturing in U.S. universities, it is important in understanding the environment from which universities are coming in attempting to transfer manufacturing technology.

A final aspect of the university environment concerns the motivations why universities would want to TT to or otherwise interact with industry. One motivation cited by most observers is the universities' need for money. Lower or level enrollments, rising faculty salaries and other costs, and reduced Federal aid - particularly funding for R&D outside of DoD sponsored research - have pushed many universities in the direction of industry. At the same time, some Federal dollars are available for this purpose, and new sources of funding from State and Local Governments are often tied to concerns for local industry development and jobs.

Peters and Fusfeld say that the need for money is an oversimplification of why universities are seeking to interact with industry today, and they provide more complex and educational reasons as follows:

(1) Industry provides a new source of money. This helps diversify the university's funding base.

(2) Industrial money involves less red tape than government money, and the reporting requirements are not as time-consuming.

(3) Industrially sponsored research provides student exposure to real world research problems.

(4) Industrially sponsored research provides a chance to work on an intellectually challenging research program which may be of immediate importance to society.

(5) Currently, some government funds are available for applied research, based upon a joint effort between university and industry.

(6) To provide better training for the increasing number of graduates going to industry. (ref. 3, p. 36)

The strongest motivation, according to their respondents in universities, was to obtain funds for strengthening basic research and graduate training and to support the research facilities used for those purposes.

In turning to the Receiver and the Receiver Environment elements, I would like to approach them from the university view point by raising the question of who the customers are or ought to be regarding university manufacturing TT activities.

First of all there is a level of industry aggregation issue. We can assume that at the highest level of aggregation, the customer base is all of manufacturing in a given locale or region. Going down one level, TT programs could be dealing with a sector of manufacturing - the metal stamping and fabrication industry, for example. Defining a customer base even at this level, however, is not very precise. Moreover, at this level we must choose between/among sectors, and have a rational basis for doing so.

One level further down would be a subset of a manufacturing sector, a group of firms in metal stamping and fabrication, for example, that can agree on some collective relationship with a university TT program. But how many - or how few - firms would have to agree, what percentage of the local sector should they represent, and what to do about the qualifying firms that do not participate are issues that remain.

At the lowest level of aggregation, there would be a one-on-one relationship between individual manufacturing firms and university TT activities which would address specific problems/opportunities.

An issue that is particularly relevant to TT activities associated with university R&D programs is how much cooperation or collective agreement can be achieved among a group of industrial customers who are competitors. Experience suggests that it is much easier to talk about the desirability of a common, collective industry approach to technology efforts in principle than it is to put such an approach into practice. Each company in a collective effort has to agree that it will be better off before it will participate, and that its position vis-a-vis competitors down the street or across the country will not be harmed. Industry leaders who have made the investments in a new technology and thereby gained a competitive advantage will be uninterested in a collective effort which helps their competitors to catch up, and may actively oppose it. Industry associations, the organizations which do represent collective industry interests, have largely been unsuccessful in forging collective research and technology efforts. Certainly the recent experience of the National Machine Tool Builders' Association, which has discussed and debated a cooperative research effort for the past eight years or more, and only now has decided to support it, provides little hope.

On the other hand, however, U.S. industry is changing in its attitude toward cooperative approaches to research. Since the passage of the National Cooperative Research Act of 1984, at least 49 cooperative R&D ventures have registered with the Department of Justice. A number of manufacturing technologies are included in the ventures listed. The pressures of international competition and survival are undoubtedly pushing U.S. firms toward a more cooperative approach domestically, and many hope that universities might have the prestige to overcome the fragmented, competing interests of much of U.S. manufacturing.

Within an industry sector, a different customer issue arises concerning a "triage" approach to companies - should university TT customers be the leading, elite companies in the industry; the threatened, about-to-fail companies in the industry; or the majority of companies somewhere in the middle? This issue revolves around the openness and ability to use technology, the need for help and/or the willingness to want and accept help.

A strictly triage approach would be to focus on the needs of the majority of companies in the middle, on the basis that the elite will make it anyway and those about to fail won't make it under any circumstances. There are other arguments, however, in favor of an elite approach. It is usually the industry leaders -

the elite - who are most open to the potential of new ideas and who respond to them. Moreover, these are the companies who would be able to most effectively utilize any technology-based program a university might design. Finally, if we expect the industry to organize collectively around some common research objective or other idea, it is the industry leaders who will have to do the organizing - and they will do so only around projects which are to their benefit as well as the benefit of the industry at large. Should universities aim their efforts at making the strong stronger, and hope some of the followers will benefit as well? Or should they aim at the weaker followers who have a chance to succeed and compete, focusing on their specific needs? In a mature, fragmented industry with stable or declining markets, is perpetuating a larger number of weaker companies better than focusing on a smaller group of stronger companies? These are difficult decisions for universities to make!

One final point regarding the customer issue. New university programs have significant institution-building needs. At the moment, state/local economic development via university/industry technology activities is very popular, and a multitude of approaches are being tried across the nation. Experience would suggest, however, that such popularity may be fleeting and that universities should seek to establish and institutionalize their industry programs while support is high. The proven way to do this is to have some "winners" as quickly as possible, consistent with good planning, quality work, and well thought through program/project selection. Such success stories are most likely to be achieved by focusing on the elite of an industry sector.

An alternate way to look at the customers of university TT programs is the distinction between large and small manufacturing companies. Two arguments are made against focusing on the larger companies: they already can and do access university technology on a regular basis without help, and in many areas they are too technologically advanced for universities to help.

Both arguments can be questioned, however. There is probably no doubt that large companies are better able to access university technology than their smaller counterparts, but this does not mean that such interaction could not be improved or strengthened. Likewise, university programs/projects for larger, technically-sophisticated companies might be more scientific in nature and require more planning and resources, but this doesn't necessarily mean they can't or shouldn't be done. Moreover, anything that improves the manufacturing of the larger companies often has a larger impact, and cascades down to their supply base among small companies.

Assuming that universities do establish TT programs/activities, can/should their output be targeted to (1) specific customers, (2) local manufacturers only, or (3) U.S. manufacturers only? This issue is made complex by the increasing number of foreign owned manufacturing operations located in the United States (can/should they be customers? what if they appear to be taking more advantage of university programs/activities than U.S.-owned manufacturers?), and the increasing number of transnational joint ventures and similar arrangements.

Looking at the environment of U.S. manufacturing receivers, most observers were as critical of the industrial community as they were of the universities, and there was some question of how much U.S. manufacturers were really changing. The following quote by Robert Frosh captures the essence of this criticism:

> From the outset, symposium participants appeared to be clearly frustrated about the state of manufacturing engineering and the status of manufacturing engineers. Apparently a major source of this frustration is a distinct (and probably correct) perception that the importance of manufacturing in the process of innovation and in the establishment of business competitiveness has been almost completely ignored for a long time. With the focus of business attention on fiscal and management areas, the art and science of manufacturing engineering have been allowed to decay, and companies have not recognized manufacturing engineering skills as high-priority ones to be highly rewarded. Rather, manufacturing has increasingly become a place to demonstrate only "managerial" skills, with more rewards given for these than for technical competence, skill, and ingenuity in the technical tasks of manufacturing. In fact, manufacturing jobs have increasingly become routes to other parts of the business and to expanding responsibility in nonmanufacturing areas.
>
> In spite of the considerable talk about the importance of manufacturing engineering, participants felt that relatively little change has occurred during the past several years in the status of manufacturing engineers in corporations...(ref. 19, pp. 1-2)

Another important factor present in the U.S. manufacturing environment in my opinion is a deep-rooted adversarial relationship between management and labor at the plant level. Implementing newly transferred, advanced manufacturing technologies is going to require extensive employee involvement, which Shea describes as a team effort with authorization and ability to make important decisions in a number of areas in real time on the plant floor. (ref. 13, p. 14) George Kuper, executive director of the NAE's Manufacturing Studies Board has described successful implementation of automation technology as a "social revolution" regarding management-employee relationships. (ref. 20) Transferring technology is a matter of people as well as of hardware.

The capacity of manufacturers to utilize technology and assimilate advances in research is also related to their absorptive capacity -- their internal technical capabilities. Unfortunately, some of the U.S. industries most in need of new technology have cut back on or even abandoned some of their R&D efforts. Participation in university R&D or TT programs is not a substitute for having an effective internal capability in this regard. The Working Group for the NAS Government-University-Industry Research Roundtable raised this issue particularly with respect to the Center for Iron and Steelmaking Research at Carnegie-Mellon University. (ref. 8)

Peters and Fusfeld remind us that one must also look at the different parts of corporations which may be engaged with university R&D or TT. They distinguish between corporate foundations for the support of external activity, central R&D labs, divisional R&D labs, and operating units. (ref. 3, p. 26) These different parts of the corporation should behave differently in their interactions with universities, including receiving technology.

Finally, it is useful to look at why corporations interact with universities to understand their environment. Peters and Fusfeld found the following reasons to be important among their corporate respondents:

(1) To obtain access to manpower (students and professors).

(2) To obtain a window on science and technology.

(3) To solve a problem or get specific information unavailable elsewhere.

(4) To obtain prestige or enhance the company's image.

(5) To make use of an economical resource.

(6) To provide general support of technical excellence.

(7) To be good local citizens or foster good community relations.

(8) To gain access to university facilities. (ref.3, p. 34)

The single most important reason was access to high quality manpower, including graduate students who are potential employees.

One of the hypotheses previously put forward was that the greater the differences between the entities on either side of a TT interface, the more difficult the transfer. The differences between U.S. universities and private industry manufacturing are pointed out by all observers, and include differences in perceptions and understandings about each other, differences that are real, and differences that are psychological. Economic needs, time pressures, tenure requirements and commitments, budget cycles, free flowing vs. proprietary attitudes toward information, etc. are some of the differences that are usually mentioned. The Working Group on Industry-University Cooperation in Education for Manufacturing grouped these differences in the following manner:

- lingering mutual suspicious arising from different cultures and value systems, especially the adversarial relations of the 1960's;
- practical considerations such as time frames and resources;
- sustained participation by industry, stability of support;
- attitudes toward knowledge and information;
- different languages used;
- different incentive structures used;(ref. 21, pp. 98-99)

Peters and Fusfeld asked about the barriers and constraints to university - industry research actions in both university and corporate samples - See Table 4 on the following page (ref. 3, p. 37). They reported that university respondents always brought up patents and licensing arrangements, pre-publication review requirements, and proprietary information issues. Corporate respondents tended to discount the first two issues as problems,

TABLE 4

Barriers to University/Industry Research Interactions Derived from Interviews with Scientists and Administrators at Institutions Surveyed in NYU Field Study

Barriers to U/I Research Interactions Cited by Interviewees	Percent of Institutions Surveyed Where Representatives Cited That Such Barriers Existed	
	Universities (n = 39)	Companies (n = 56)
1. Patent conflicts (patent and licensing arrangements including whether or not to issue an exclusive license).	100	23
a. Patent conflicts	67	23
b. Legal problems	38	0
2. Information dissemination	100	43
a. Proprietary rights	74	32
b. Prepublication review	33	11
3. Institutional differences	79	52
a. Differing objectives and goals*	18	21
b. Differing administrative structures**	28	13
c. Time frame differences	33	18
4. Personal attitudes	36/13 as a barrier to industry	16
5. Communication networks	28	5
6. Distance	23	20
7. Concern for research facility and management**	21	11
8. Carreer constraints	21	4
9. Overhead costs*	15	4
10. Decreasing federal funds	0	4
11. Company expertise in a particular area	0	2

* Cited more often by administrators.
**Cited more often by scientists.

and to think of the third as not that important, believing that these differences were negotiable. They tended to think that institutional differences were more important.

This corporate view is supported by what the NSF found in looking at the experiences of their cooperative research centers. They found that the issues most hotly debated during the planning phases - patents, publication delays, and the relative priority of basic and applied research - tended to become "non-issues" by the time operations were underway. On the other hand, important operational issues such as pressure for results, reporting procedures, and time allocations, were hardly considered during planning. (ref. 4, second edition, pp. v and vi)

As previously indicated, the <u>technology</u> of how to <u>manufacture</u> products is extremely broad based and diverse. Shea perhaps describes it best as follows:

> Manufacturing is a process which transforms information into a product. The information includes design data, quantities required, and delivery dates. The transformation involves developing tools and processes, obtaining material, processing material, assembly, testing, and delivery. The factory of the future will be an integrated system with a common engineering and manufacturing data base. Data processing will be used extensively to receive design information without having to reconfigure for manufacturing, estimate and order material, control inventory, program machines, monitor yields, and program test equipment. Automation will be extensive, encompassing material handling, numerically controlled machines, and closed-loop process control. Robots will function as welders, painters, assemblers, and inspectors.
>
> New materials with advanced properties will displace conventional products and processes... the factory of the future will challenge our long-held belief that high-volume runs of identical products are required to achieve low cost... their ability to produce quality products tailored to special customer requirements on a very short lead time... the "just-in-time" production concept... finely focused factories...flexible layouts... group technology ... the defect level must be reduced to as near zero as possible... minimal set-up times... (ref. 13, pp. 11-13).

Manufacturing technology, in this view, includes the entire spectrum of manufacturing concerns, encompassing both hardware technology and business management. It should be apparent that the problem in defining manufacturing technology is not a lack of materials or ideas, but how to organize them, prioritize and sequence them, synthesize them, communicate them, transfer them. Any university TT program in manufacturing will have to deal with a plethora of potentially relevant "technology" that is at once changing and growing.

What many observers do agree on in this situation is that manufacturing technology is best thought of from a systems viewpoint - systems which include hardware and people, engineering and business.

I view manufacturing as a process flow, so that biotech fermentation and polymer processing are included in my definition of manufacturing. The "how-to" of manufacturing in the metal-based industries, however, suffers from a relative lack of fundamental scientific, data-based knowledge of what actually happens and why in individual operations. In a chemical plant, we know scientifically how and why chemicals interact with each other and with temperature, pressure, time, catalytic, and other variables to form specific compounds, and chemical plants operate effectively on this basis. Many metal-based operations - e.g., tool and die design - are still somewhat in the realm of craft and art, contained in the minds of experienced, skilled artisans. Although this is gradually changing as the science base of metal manufacturing does increase, attempts to express the details of complex, incompletely understood operations in terms of computer code for automation purposes is bound to present difficulties.

Two final points about technology with regard to university programs. The first concerns the role of technology in a business operation. Universities should not pursue technological options in manufacturing for their own sake, but technology to support effective competitive strategies for the industry sector/company customers. Successful technology development and/or transfer which has little or no strategic relevance could have little or no impact on the programs' ultimate objectives.

The second point concerns time perspectives - should university programs/activities have a near-term or longer-term time horizon? The argument for the former is that there is no longer-term if U.S. manufacturing does not survive in the short-term. The counter argument is that there can only be quick-fix, band-aid solutions in the short term which do not address the real competitive problems and in the long term are a waste of money.

A great variety of linkage mechanisms used for TT by U.S. universities have already been identified in earlier portions of this paper. In the long-term, perhaps the most valuable contribution universities can make to manufacturing is to enhance their manufacturing education and placement efforts. In education, more has to be done in developing curricula in manufacturing engineering and management. Specialized, short educational offerings in important areas of manufacturing technology and continuing education programs can address the needs of manufacturing managers and engineers already graduated.

Small manufacturers often have a special problem with regard to attracting qualified graduates in systems/applications engineering. Such graduates, already in short supply, tend to gravitate toward the IBMs of the marketplace rather than, for example, small metal stampers and fabricators. Universities might be able to help in this area through specialized graduate placement programs and through internship, co-op, summertime, or part-time programs which combine education and work experience.

As we move beyond the education mechanism for TT, a variety of new forms of interaction occur. Basic research programs may be accommodated within traditional university departments and schools, but more applied work and TT are usually undertaken outside the traditional academic organization in centers, incubators, research parks, etc.

Peters and Fusfeld documented the "mechanisms of interaction" utilized by the university programs they studied, and divided them into four major categories - general research support, cooperative research support, knowledge transfer, and technology transfer. Some examples of these mechanisms and the number of programs falling into each category are shown in Tables 5 and 6 on the following page. (ref. 3, p. 16) The university-industry cooperative research programs are further broken down into sub-mechanisms, reflecting the main focus of the study. I shall focus on the knowledge and technology transfer mechanism categories - 58 programs falling into knowledge transfer and 68 into technology transfer.

Some knowledge transfer programs may have knowledge transfer as their main purpose, while others may not. They are frequently essential elements in other programs that promote research

TABLE 5

Examples of Selected Mechanisms of Interaction

Mechanism of Interaction	Examples
University-Based Institutes Serving Industrial Needs	• Textile Research Institute • University of Michigan Highway Safety Research Institute • University of Minnesota Mineral Resources Research Center • Food Research Institute, University of Wisconsin
Jointly-Owned or Operated Laboratory Facilities	• Laboratory for Laser Energetics, University of Rochester • Peoples Exchange Program, Purdue University • Synchrotron Light Source, Brookhaven National Laboratory
Research Consortia (U/I or U/I/Gov't.)	• Michigan Energy and Resource Research Association • Council for Chemical Research (CCR)
Cooperative Research Centers	• Case Western Reserve Polymer Program • University of Delaware Catalysis Center
Industry-Funded Cooperative Research Programs (Partnership Contracts)	• Harvard-Monsanto Contracted Research Effort • Exxon-MIT • Celanese-Yale
Government-Funded Cooperative Research Programs	• MIT Polymer Processing Program • NSF Industry-University Cooperative Research Program
Industrial Liaison Programs	• Stanford University • MIT • CalTech • Systems Control, Case Western Reserve University • Physical Electronics Industrial Affiliates, U. of Illinois • Wisconsin Electric Machines & Power Electronics Consortium, U. of Wisconsin
Innovation Centers	• Center for Entrepreneurial Development, Carnegie-Mellon U. • Utah Innovation Center
Personnel Exchange	• NSF Industrial Research Participation Program • IBM Faculty Loan Program • Summer Employment of Professors
Institutional Consulting	• School of Chemical Practice, MIT • Yale-Texaco Program • Mechanical & Manufacturing Systems Design, Clemson U.
Industrial Parks	• Research Triangle Park • Stanford Industrial Park • MIT Technology Square (Route 128, Boston, MA) • University of Utah Research Park
Unrestricted Grants to Universities and/or University Departments	• Gifts from industry to departments of chemistry (e.g., Columbia University; U. of North Carolina (Chapel Hill); U. Illinois, etc.)
Participation on Advisory Boards	• Visiting committees at most schools of engineering
Collective Industrial Action (Including Trade Associations Support)	• Electric Power Research Institute (EPRI) • American Petroleum Institute (API) • Gas Research Institute (GRI) • Motor Vehicle Manufacturers Association • Soybean Association • Council for Chemical Research (CCR)

TABLE 6

The Spectrum of Interactions Documented in NYU Field Study

Types of Interactions	% of Interactions Documented Falling Into Each Category	(N)*
All Categories of Interactions	100	(464)
• General Research Support	11	(54)
• U/I Cooperative Research	61	(284)
• Knowledge Transfer	13	(58)
• Technology Transfer	14	(68)
U/I Cooperative Research (Selected Categories)	100	(284)*
• Special Interest Liaison Programs	23	(65)
• U/I Cooperative Research Centers & Institutes	25	(71)
• Research Consortia	5	(15)
• Grants & Contracts	45	(128)
• Collaborative Interactions	2	(5)

*Total Number of Interactions Falling Into Each Category interaction. They include a variety of forms of personal interactions between university and industry personnel (personnel exchanges, equipment lending, advisory boards, seminars, speakers' programs, publications exchange, adjunct professorships, consulting, etc), a variety of institutional programs (institutional consulting, general industrial associates programs, etc.), a variety of research and educational mechanisms already mentioned, and a variety of collective industrial actions in support of university research (trade associations, affiliates of trade associations, independent R&D organizations affiliated with a university, and industrial research consortia). (ref. 3, pp. 85-98).

Technology transfer programs to expedite the commercialization of technology have a long history in agricultural fields in many universities. Specific university TT mechanisms discussed by Peters and Fusfeld include product development and modification programs (extension services, innovation centers), and interaction facilitating programs (technology brokering and licensing, university research institutes/foundations, industrial parks, spin off assistance). (ref. 3, pp. 98-107)

Finally, I will make a few points about the environment in the United States within which university-industry TT is taking place. The dominant factor in the United States environment today is the concern about international competitiveness. As the preface to the NAS Government-University-Industry Research Roundtable report on "New Alliances and Partnerships in American Science and Engineering" states:

> Competitiveness is currently all-important in our society. Conversations about where science is going in this country, and which fields and programs will receive support, all start with international competitiveness - spelled with capital letters. How we approach competitiveness colors everything in university - industry alliances... (ref. 8, p. ix)

This concern for competitiveness cascades down into many areas - a back-to-basics swing in U.S. education, a renewed emphasis on product quality, etc. In university-industry relations, it has meant more attention and more money - from the Federal government, from industry, and particularly from state and local governments.

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