Information and Technology Exchange Among Engineering Research Centers and Industry: Report of a Workshop (1985)

Pages
64

Size
5 x 8

ISBN
0309322480

Workshop Steering Group; Cross-Disciplinary Engineering Research Committee; Commission on Engineering and Technical Systems; National Research Council

INFORMATION AND TECHNOLOGY EXCHANGE AMONG ENGINEERING RESEARCH CENTERS AND INDUSTRY

REPORT OF A WORKSHOP

Washington, D.C., June 11, 1985

Workshop Steering Group
Cross-Disciplinary Engineering Research Committee
Commission on Engineering and Technical Systems
National Research Council

Order from
National Technical
Information Service,
Springfield, Va.
22161
Order No. PB86-163185

National Academy Press
Washington, D.C. 1985

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This activity was supported by the National Science Foundation under cooperative agreement No. ENG-8505051 between the Foundation and the National Academy of Sciences. The opinions, findings, and conclusions or recommendations are those of the Workshop Steering Group and the speakers and do not necessarily reflect the views of the National Science Foundation.

Available from:

Executive Office
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2101 Constitution Avenue, N.W.
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Report No.: CETS-CROSS-2

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PREFACE

This is the report of a workshop held to examine issues relating to the topic Information and Technology Exchange Among Engineering Research Centers and Industry. It was the first of a series of workshops that will focus on various issues expected to be important in the management and operation of the Centers. The workshop was organized under the auspices of the National Research Council's Cross-Disciplinary Engineering Research Committee, which was established on January 1, 1985 to respond to the request of the National Science Foundation (NSF) for assistance in reviewing the programs and management of these innovative research Centers.

The expressed goal of the Engineering Research Centers (ERCs) 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." Therefore, an important aspect of the Centers' function will be to communicate and expand that knowledge through the exchange of information and technology with other ERCs, with private industry, and with various other interested research organizations.

The workshop was held in Washington, D.C. on June 11, 1985. It was attended by 37 representatives of academe, industry, and government, who provided their views and suggestions on many different aspects of this complex topic. This report presents a distillation of those opinions and suggestions, along with papers presented by the members of the Workshop Steering Group at the beginning of the meeting. We hope that the NSF will find the report useful in guiding the early development of those essential institutions, the ERCs.

Steering Group
Don E. Kash
James F. Lardner
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SUMMARY

In 1985 the National Science Foundation (NSF) initiated a program to support the establishment of cross-disciplinary Engineering Research Centers (ERCs) focused on a wide range of research areas critical to the international competitiveness of U.S. industry. The mission of the Centers is both to produce new knowledge in these areas and to prepare engineering graduates with the capabilities needed by industry. Their underlying objective is to introduce new elements into the culture of academic and industrial engineering--new ways of thinking, of conducting research, and of educating students that are appropriate to the cross-disciplinary, problem-oriented approach to be taken by the Centers.

The focus on cross-disciplinary effort means that communication--among the disciplines as well as among the academic and industrial organizations involved--will assume considerable importance in the ERC program. The purpose of this workshop was therefore to advise the NSF as to ways in which the ERCs could be encouraged to establish a continuous exchange of information, technology, and ideas with the community of interested engineering researchers and practitioners.

The overriding conclusion that emerged from the workshop is that the NSF should resist the temptation to mandate specific communication programs. The ERCs represent a novel and very important experiment, so there are no established formulas for success in any aspect of their operation. Moreover, what works for one ERC in one location will not necessarily work for another. Therefore, it is the conclusion of the workshop participants that each ERC should be allowed to establish its own information exchange network, and to experiment over time with the specific mechanisms and procedures that appear to work best. As a general guideline, it was stipulated that this network must be primarily a community of people--individuals who will interactively share information, technology, and ideas relevant to the Centers' work.

Beyond those general conclusions, the report of the workshop describes a wide range of specific mechanisms that represent options for establishing such a community and for facilitating the development of exchange networks. These options are listed, without discussion, below.

1. Each ERC should develop a clear statement of its goals and plans, and publish this statement as widely as possible within its constituent community.
2. Responsibilities relating to the information/technology exchange program should be specifically assigned by the Center director.
3. Mechanisms for bringing university and industry people together include:
   - Industry Advisory Councils
   - Research Advisory Committees
   - Topical Review Conferences
   - Symposia
   - Resident Programs
   - Short Courses
   - Academic Courses
4. Mechanisms for cooperative research include:
   - Joint Development Projects
   - Shadow Teams
   - Standard Joint Research
5. Linkages with other organizations and institutions include:
   - Other Universities
   - Government Laboratories and Nonprofit Research Centers
   - Venture Capital Firms
6. A variety of specific information media were identified as possible options; these include:
   - Newsletters
   - Electronic Mail
   - Annual Reports on the ERCs
   - Directory of Researchers
   - Audio Conferencing
   - Professional-society Meetings
   - Journal of Cross-Disciplinary Research
   - Other Publications
   - Telephone and Letters

7. There are a variety of special issues that relate only indirectly to information/technology exchange, but that were considered; certain other questions relate directly but are problematical, and thus deserve separate discussion. These include:
   - Linkage with Foreign Firms
   - Monitoring Foreign Research
   - Linkage with Nonparticipating Undergraduates
   - Consulting
   - Review of Information Exchange Program
   - Linkage with Small Companies

Part I: INTRODUCTION

THE ERC PROGRAM

In 1985 the National Science Foundation initiated a program to support the establishment of cross-disciplinary Engineering Research Centers (ERCs) at universities around the nation. The first group of six awards was announced in April 1985; the NSF expects eventually to establish at least 25 ERCs.

These Centers are designed to meet national needs "for providing cross-disciplinary research opportunities for faculty and students, for providing fundamental knowledge which can contribute to the solution of important national problems, and for preparing engineering graduates with the diversity and quality of education needed by U.S. industry."* Thus they have a dual mission in engineering research and education.

The driving force behind the ERC program is a concern on the part of government about the nation's international economic competitiveness and its continued leadership in a wide range of technology-intensive industries. Weaknesses in engineering that jeopardize our ability to compete internationally also jeopardize our economic well-being, which is in turn an important component of our overall national security.

It has become increasingly clear in recent years that the specialized, discipline-based approach to engineering that has predominated in the post-World War II era is not fully adequate to meet the challenges of today's technological society. Advanced and emerging fields such as computers, automated manufacturing, composites, biotech-

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*From the NSF program announcement, "Engineering Research Centers, Fiscal Year 1986".

nology, and telecommunications require a multidisciplinary effort. This is true both in the context of academic research and in the context of industrial research and practice--in fact, the multidisciplinary approach has already made considerable headway in U.S. industry. The objective of the ERC program is to stimulate this "cross-disciplinary" approach within the academic research and teaching environment.

PURPOSE OF THE WORKSHOP

The focus on cross-disciplinary effort means that communication will assume considerable importance in the ERC program. New channels of communication need to be opened and maintained among traditional disciplines within the ERCs, as well as in the private companies with which they interact. In addition, the exchange of information and technology among the Centers and their industrial and academic constituencies is an important element of the Centers' mission. NSF has funded an initial six ERCs, and the program is expected to continue to expand. The Foundation would like to provide guidance that will be useful to the Centers, both current and future, in successfully fulfilling their role.

The purpose of this workshop was therefore to advise the NSF as to guidelines and suggestions that the Foundation could provide to ERCs for establishing a continuous exchange of information, technology, and creative ideas. It is hoped that the participants in this exchange will comprise an interactive community of engineering researchers and practitioners from both academe and industry. Some 30 representatives from the ERCs, industry, and the NSF were invited to Washington to participate in the one-day meeting and to offer their suggestions and guidance on ways to facilitate communication.

Part II of this report presents the results of the workshop. Those results are divided into two categories: first, a discussion of "General Findings," and second, a listing of numerous "Specific Options" for establishing an information/technology exchange. Finally, three presentations given at the workshop by Steering Group members are included as an Appendix.

Part II: RESULTS OF THE WORKSHOP

GENERAL FINDINGS

One of the primary objectives of the ERC program is to link academic engineering research more closely to industry and to industrial needs. The establishment of effective linkages between the ERCs and industry requires that a system be developed to permit a continuous exchange of information, ideas, and technology.

This system (or systems) should be the central ingredient in the formation and evolution of interactive university-industry communities of researchers and practitioners involved in various fields. As those fields are structured not around traditional disciplines, but around world markets for technology, the emergence of these communities is viewed as essential to the nation's future technological competitiveness and economic well-being. It should be noted that what is involved here is not just an exchange, but the development of new institutions and new ways of carrying out engineering research and practice.

Effective information/technology exchange depends on the existence of both common needs and common benefits among the parties involved. We are impressed with the unanimity of support for the ERCs--this is clearly an idea whose time has come. The broad industry-university support for establishment of the Centers gives ample testimony to the need for such an approach. A deliberate concern for the exchange of useful information and technology can be a significant factor in ensuring that common benefits are derived from the work of the Centers. Indeed, we anticipate that an exchange system will be fundamental to the success of any given ERC.

As was noted in the introduction, the cross-disciplinary focus of the Centers is impelled by contemporary technological and economic realities. In a technological society, engineering takes on different characteristics than it exhibits in an industrial society. The need for synthesis, for integration--for a cross-disciplinary approach--becomes greater. Not only does engineering need to be practiced in new ways; it also needs to be researched and taught in new ways.

The focus of the Centers on cross-disciplinary engineering research and teaching is both essential and difficult. It is essential and difficult for industry as well as for universities, but for universities in particular this approach requires fundamental changes in established modes of thinking and action. In short, it involves a change in the culture of engineering research and education. The ERCs are the instruments of that change. But a close and continuous interaction with industry is essential to making this cultural transition successful. Indeed, an important part of the cultural change is the need for academic engineering research to reflect more closely the realities of industry practice and industry needs. As Dr. Roland W. Schmitt, Chairman of the National Science Board, asserted in his address to the National Research Council Symposium that introduced the ERCs:

> I believe that the main way in which engineering research and education can contribute to the international competitive position of the United States is by bridging and shortening the gap between the generation of knowledge and its application in the marketplace . . . We need wider and stronger bridges between the people doing engineering in industry and the people teaching engineering and doing research in universities.

The flow of new cross-disciplinary knowledge and engineers trained in the new environment will, over the long term, add substantially to the competitiveness of American industry. Indeed, we hope that young engineers quickly come to see this kind of work as a way to contribute to the achievement of important national goals. Similarly, it is important for bridges of communication to be built into the existing engineering disciplines, as the results of cross-disciplinary research can certainly strengthen them.

If, as we believe, the maintenance of continuous and close exchange among ERCs and industrial organizations is essential to the success of the ERCs, then there is a powerful temptation for the funding agency (whether NSF or another) to mandate those communication linkages. This temptation must be resisted. Nothing seems more clear than the fact that, with the Engineering Research Centers, the nation is involved in a great experiment. It is an experiment precisely because there is no established formula that can be assured to work. Perhaps even more important, what works for one ERC with a specific focus and in a specific location will not necessarily work for another. All we can say for certain is that it is essential for the ERCs to be committed to the effective exchange of information and technology.

Therefore, we conclude that each ERC should be allowed to establish its own information exchange network, and to experiment over time with the specific mechanisms and procedures that appear to work best. The exchange network will not spring forth full-blown. It will develop gradually, as industry and the ERCs get to know one another.

As a general guideline, this network must be primarily a network of people. Workshop participants were unanimous in their belief that any such exchange must be built on interpersonal contacts if it is to be successful. Each ERC must strive to establish and involve in its network a community of people interactively sharing information, technology, and ideas relevant to the Center's work. The ERCs should not try to predetermine the makeup of their community; but they should attempt initially to identify some of the most likely potential exchange partners. If at all possible, individuals within companies, rather than just companies per se, should be identified. Appropriate people can be best identified by contacting division-level managers.

Given these general observations and conclusions, in the following sections we will suggest a variety of specific mechanisms that represent options for establishing such a community, and for facilitating the development of exchange networks. All these suggestions support the notion of people-to-people exchange. They comprise a "shopping list" that can be used by ERCs for guidance as they begin to experiment with exchange networks.

SPECIFIC OPTIONS

1.0 GOALS STATEMENT

Fundamental to the success of any cross-disciplinary research effort is a commonly shared understanding of the long-term goals of the organization and the nature of the effort in which it will engage. This common understanding is important in the relationship between the ERC and industry, as it creates a framework for information exchange. It is also important for ensuring clarity of purpose and direction within the ERC; and it is important in the relationship between the ERC and the university.

Accordingly, we recommend that each ERC develop a clear, concise statement of its goals and overall plans, and publish this statement as widely as possible within its constituent community.

2.0 RESPONSIBILITIES

Given the importance of information/technology exchange, this function must not be left to chance. Communication is a definable task, and responsibility for it should be assigned. The Center director should take ultimate responsibility for seeing that it is done properly and effectively; but responsibility for various aspects of it can be delegated.

There is a range of options here. Individual faculty members might have collateral responsibilities in this regard. Alternatively, technical information specialists might be hired for this purpose (e.g., in an Office of Industrial Participation, or as group liaison specialists). It might be deemed necessary for a separate staff to be employed to carry out the more mechanical activities associated with the information exchange program (i.e., coordination, mailing, recordkeeping, etc.). For more highly technical exchanges, it might be appropriate for individual researchers to be assigned responsibility for maintaining communication with specific firms and/or industries.

3.0 MECHANISMS

This section provides the most detailed options, and is thus divided into four subsections.

3.1 Mechanisms for Bringing University and Industry People Together

As was mentioned above, the foundation of the ERC information exchange programs should be person-to-person contact. In the context of ERC goals, the most important type of interaction is that between an ERC and private companies. A number of general observations can be made about the nature of these interactions.

First, it is important for university and industry people to be brought together in both the university and industry settings. This provision will facilitate the two-way-street nature of the exchange. Second, to the extent possible there should be a stable membership of people involved; fruitful exchanges can occur only where both parties are familiar with each other's personalities, work, and needs. Third, there will probably be a hierarchy of mechanisms employed, involving different levels of interest and commitment on the part of industry. Levels might range from the receipt of general information to the exchange of detailed research results or technology, and to input on the direction of ERC research.

Options for specific mechanisms that might be employed to bring university and industry people together include the following:

Industry Advisory Councils

Such bodies would be comprised of executives of corporations that have a substantial commitment to an ERC's research program. The council is intended to maintain high-level managerial support for that commitment. The council should meet at regular intervals (e.g., three times a year), and members should be provided with periodic frank reports on progress and activities of the Center.

Research Advisory Committees

Such groups would be essentially second-tier versions of the councils described above; but they would have a more active and substantive role. A committee would consist of technical specialists able to brainstorm research problems with their ERC counterparts. Members could function as advisors on technical issues, thus providing a resource similar to the use of outside advisors and consultants by industry. These advisors would be able to generate new synergies within the research program by informing the ERC of relevant work in industry (not only within their own company). This second-tier group could also encourage cross-fertilization among different industries involved with the ERC.

Topical Review Conferences

These can be structured as informal social meetings that bring together industry and ERC researchers for discussion of research projects. They can be focused on selected topics, or left open. Their primary purpose is to transfer information and ideas and to stimulate creativity. One point that may be relevant here is that small groups (15 persons or less) are more conducive than large groups to real participation--everyone has a chance to speak, and individuals are not intimidated by the size of the group.

Symposia

These and other meetings can be held from time to time for relatively large audiences. They might be keyed to significant progress or breakthroughs in a general area of research; clearly they would be somewhat general in content.

Resident Programs

The exchange of people for varying periods of time between the ERCs and industry should be encouraged and supported. Sabbaticals in both directions are desirable; this could be a particularly useful mechanism in the case of small companies, which may have difficulty with the cost of freeing-up people. Companies able to support a heavy commitment may find that having an on-site representative at the ERC is a very beneficial arrangement. Visiting Scholar programs and short visits by industry or ERC personnel to the other's facilities should also prove valuable.

Short Courses

Devised for technology transfer, such courses are regularly offered by the Semiconductor Research Corporation to its member companies; the composites research center at the University of Delaware also offers them. They are typically a three-day crash training program for moderate-sized groups (about 30 people). A novel approach might be for industry to create practice-oriented courses for university researchers.

Academic Courses

Undergraduate instruction is an important part of the ERCs' mission, and the flow of information from industry into the education process is a major element of it. Team teaching with industry people should be tried where appropriate; industry can provide adjunct professors as well. New courses can be developed from the work of the ERCs. And cooperative education programs with industry can give students the opportunity to gain valuable hands-on experience and practical attitudes. Ultimately, the ERCs might even generate new curricula and new degrees geared more closely to industry problems than are the traditional disciplinary degrees.

3.2 Mechanisms for Cooperative Research

The conduct of joint research offers great potential for technology transfer in both directions, and is the best means for ensuring that ERC research is focused on the actual problems and needs of industry. Some options are described below.

Joint Development Projects

An excellent way to facilitate the exchange of information and technology is the design and development of prototypes. Joint activity of this kind can have substantial educational as well as research benefits. However, such work can also generate serious concerns of a proprietary nature, which in turn can impede the open and free flow of information, and damage the trust upon which effective interaction is based.

Because conflicts over confidentiality and proprietary information could have a serious detrimental effect on the communication and cooperation that are essential for support of the Centers, each ERC director should be sensitive to the need to define carefully the terms of all such arrangements in advance. In particular, each ERC needs to investigate the information-exchange advantages and disadvantages of patents on a case-by-case basis. Generally speaking, patents, by demanding disclosure of the best of the art, will stimulate competitiveness, and are therefore to be encouraged.

Shadow Teams

The use of shadow teams in industry, working on research projects parallel to those of the ERCs, is encouraged. Such a project would consist of testing and modification of the ERC research output, so as to tailor it to the needs of the individual company.

Standard Joint Research

This mechanism would involve participation of industry personnel in ERC research teams. The level and extent of participation will of course vary, depending on the situation and on the wishes of the individual company.

3.3 Linkages with Other Organizations and Institutions

If the work of the ERCs is to have the greatest possible benefit for the technological competitiveness of the nation, then the exchange network will have to be extended to a broader community than that represented by the ERCs and industry. Some possibilities are described below.

Other Universities

In their focus on cross-disciplinary, project-oriented research, the ERCs represent a potential model for other engineering schools--especially for the nonresearch institutions which graduate roughly half of all U.S. engineers each year. Faculty from other universities should be able to visit the ERCs for short- or long-term residence. Not only will this contribute to information exchange; it will also give visiting faculty a chance to see how the culture of engineering research and education is altered by the ERC (i.e., the greater emphasis on creation of new products and processes, and the exposure of students to the entire process of technology development from idea to product to commercialization).

Government Laboratories and Nonprofit Research Centers

There are significant information-exchange advantages to be gained by linking the national laboratories and/or nonprofit research organizations to the ERC information networks. Government labs and nonprofit organizations have traditionally played an important bridging role between the universities and industry (or vice versa). The ERCs will now play a comparable role--although geared more toward application and commercialization--so there is a natural commonality of interests.

Venture Capital Firms

In some instances, utilization of ERC research may be facilitated by establishing information exchange links with the venture capital community. Of course, this is not generally a viable route in the case of declining industries, but it is an option that each ERC should at least consider. Indeed, one way of demonstrating the success of an ERC might be to count the number of start-up companies that result from ERC input.

3.4 Information Media

Many of the more continuous and/or mechanical aspects of the ERC information exchange network can be served by the use of various information media. These need not be innovative or state-of-the-art; many of the options are quite mundane. However, once in place, they can be both effective and cost-effective for reaching a wide audience, at different technical levels and with a lower investment of staff time. A large number of possibilities were discussed at the workshop. Some of the most promising are:

Newsletters

Newsletters are an effective means of keeping large numbers of people up to date on Center activities and getting new companies involved with the Center programs. The content and format of a Center's newsletter will depend on the nature of its work and on the industrial readership. In general, it should be written at the level of the technically oriented nonspecialist, and should convey a "global" picture of Center research. A newsletter is a good vehicle for overcoming the fact that only a small percentage of the R&D staff of most participating companies would be able to attend meetings.

Electronic Mail

The various forms of electronic mail can be used to develop a sense of community among researchers in the university and industry. The network can be used for such purposes as sending messages between individuals, on-line publication of research reports, computer conferencing, and electronic bulletin boards. The latter can be used to give notice of upcoming seminars and meetings, as well as other items of general interest. Bulletin boards might also include a one-page precis of ongoing or completed research, and perhaps might have a "mailbox" slot for interactive comments and suggestions from users. An editor should be included to keep the bulletin board up to date.

Annual Reports on the ERCs

The NSF should issue an annual report describing the ERC program. The report should summarize the research progress and results accomplished at each ERC during the year. It should be widely distributed and generally available.

Directory of Researchers

To facilitate contacts by industry, each ERC might publish a "yellow pages" directory of the people working at the Center. This directory would include names of researchers and their specific areas of research, cross-referenced by specialty groupings.

Audio Conferencing

This mechanism allows people to listen in remotely via telephone or speakerphone to seminars, conferences, and other meetings. In some cases it can be partly interactive--i.e., listeners can ask questions or make comments at appropriate times. Such phone-in conference systems should be easy to use, so that remote attendees can dial in and drop off easily and unobtrusively. Available meetings can be advertised in company or ERC newsletters.

Professional-Society Meetings

The NSF should encourage engineering professional societies to devote tutorial and special sessions at their annual meetings to the work of the ERCs. These presentations would be made by ERC staff members. Such sessions would spark greater understanding of and interest in the work and the philosophy of the ERCs.

Journal of Cross-Disciplinary Research

The possibility of such a journal has been widely discussed as a way to offer younger faculty (in particular) the means to publish the results of their cross-disciplinary work. However, it was the consensus of the workshop that a national journal of this type would not succeed because it could not be tightly enough focused. The only potentially workable option appears to be limited journals published by individual Centers or by related groups of Centers in a relatively well-defined area, such as manufacturing.

Other Publications

A wide range of other possibilities exist for publications that could enhance the flow of information and technology. Special technical reports will probably be issued (some in the form of a thesis) when a project is completed, or when significant milestones are achieved. Another idea is an encyclopedia of relevant technologies, prepared by the Center and given to supporting companies and/or sold to the public.

Telephone and Letters

The lowly telephone and the U.S. mail should not be overlooked as mechanisms of information exchange. For maintaining a nearly continuous interpersonal contact at very low cost, these mundane media are unsurpassable. Their use should be encouraged often by the Center director. The "call forwarding" feature of telephones and simple answering machines are good ways to avoid the perennial problem of the unanswered faculty telephone. Such small irritants can seriously impede communication.

4.0 SPECIAL ISSUES

There are a variety of questions that relate only indirectly to information/technology exchange, but that should be considered; certain other questions relate directly but are problematical, and thus deserve separate discussion. These special issues are discussed below.

4.1 Linkage with Foreign Firms

The question of whether to afford or deny foreign firms (or governments) access to ERC facilities and research is a thorny one. It was not within the scope of this workshop to examine the question in detail. Instead, it is likely to be a decision that is made on political grounds at the higher levels of government. However, some observations may be useful. It was the consensus of the workshop that denial of access to foreign firms is not a very effective way to stop the leakage of technology; research publications and secondary sources are always soon available. More to the point is the frequently uneven nature of information exchange with technical specialists from other countries--such exchanges should not be a one-way street.

Workshop participants felt that if foreign representatives are permitted access to the ERCs, ERC policy should adamantly insist that access cannot be continued without full reciprocity in any technical exchange. That is, equivalent mutual benefit must be gained.

4.2 Monitoring Foreign Research

Where possible, it would be valuable if individual ERCs could monitor and make available technical information originally published in foreign languages. In many instances, work being done in foreign countries may be of equal or greater sophistication than that being done in the United States. Clearly, the U.S. research community could benefit from better access to material appearing in foreign research publications. Of course, any such monitoring, translation, and reportage of material from foreign-language sources, if it is to be effective, must be done by people who are both technically competent and fluent in the language of the publication.

Although the workshop did not address this issue in sufficient detail to make a firm recommendation, it did communicate the sense that the United States needs a much broader-based capability to tap foreign-language materials than presently exists.*

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*A National Academy of Engineering study of "International Cooperation in Engineering," now under way, should address this topic and related issues.

4.3 Linkage with Nonparticipating Undergraduates

Each ERC will involve a certain number of the university's undergraduate students in its research program. But there are limitations in the number of slots available. To achieve the broadest possible beneficial impact on the education of undergraduate engineering students, the ERCs should open their programs to nonparticipating students at the university. Likely measures might include: (1) permitting student observers at all symposia and workshops; (2) hosting an open-house day for undergraduates, with tours of the facilities (these could be directed by participating undergraduate students to increase the prestige factor of the ERCs in student eyes); and (3) offering new courses, team-taught courses, and video-tape instructional material for credit.

4.4 Consulting

Consulting by ERC researchers with industrial organizations is another controversial topic, as it is in the case of university engineering faculty generally. ERC staff may be much in demand as consultants, and the tendency for ERCs to become "body shops" will have to be strenuously guarded against. However, consulting is a very effective means of information exchange and technology transfer between ERCs and industry. As such, it should be encouraged so long as it does not disrupt or impede the progress of the Centers toward their stated goals.

4.5 Review of Information Exchange Program

Periodically, a meeting of people from the various ERCs and associated organizations should be held to review the information exchange programs of the Centers. The purpose of such meetings should not be to evaluate the programs, but rather to identify mechanisms that have been successful in promoting exchange, so that the Centers can benefit from each other's experience. Such meetings would also facilitate the linking of Centers with each other, where appropriate.

4.6 Linkage with Small Companies

Compared to large companies, small companies in any industry are characterized by narrower, more specific interests, and greater difficulty in making people and funds available for effective participation in "extra-curricular activities" of the sort suggested by ERC information exchange programs. Therefore, there were some reservations among workshop participants as to whether the ERCs could involve small businesses in a significant way.

However, in many industries small companies are a natural focus of ERC interest. They may be the fastest-moving and most advanced companies, as in the electronics and biotechnology industries; or they may be a bottleneck to progress, as in the case of many small machine shops, where new technologies are desperately needed but are not being rapidly introduced. In any case, small size in some cases gives companies an ability to change quickly under the right circumstances. Thus, small companies may offer important and innovative opportunities for ERC cooperation. In some instances, such linkages may be a route to increased U.S. competitiveness.

CONCLUSION

We would reemphasize, in conclusion, a point made in the introduction: all of the options described above focus on the need to build networks that establish communities of people. Indeed, this was the single dominant theme of the workshop. Only through linking people who have diverse specialities and interests and who are located in diverse institutions will the nation have the synthetic creativity necessary to assure future U.S. technological leadership.

APPENDIX:
PRESENTED PAPERS

NEED FOR AN ENGINEERING RESEARCH CENTER INFORMATION EXCHANGE NETWORK

Don E. Kash

The Workshop on Information and Technology Exchange Among Engineering Research Centers and Industry has as its goal the identification of techniques, procedures, and arrangements that will contribute to the efficient and effective exchange of information between the Engineering Research Centers (ERCs) and private industry. Its organizers hope that, by the conclusion of the workshop, it will be possible to specify a number of actions that the National Science Foundation might take to encourage and facilitate information exchange as it develops its program of support for the ERCs.

A good starting point is to restate the reason for the new ERC program. The program's basic assumption is that the future economic competitiveness of the United States rests heavily on the existence of a national technological capability to produce innovative new products and processes. It has become increasingly evident that such technological virtuosity demands the integration of information, skills, knowledge, and capabilities from a diverse set of engineering and science disciplines. This integration requires more than simply piecing together in already-known ways various discrete specializations. Technological integration involves a synthesis that can produce a degree of innovation greater than the sum of the parts.

The problem that the Centers seek to address is that universities are intellectually, culturally, and organizationally inclined to focus on the parts rather than on the whole. Universities have traditionally found it difficult to integrate information from various sources or to carry out cross-disciplinary team research. The goal of the ERCs, then, is to overcome that problem--to build within the nation's research teaching institutions the capability not only of doing problem-oriented engineering research but to turn out engineers who work effectively in this "synthetic" context.

In the industrial era, when the great economic success of the United States rested on high-volume, standardized production, university research and teaching that focused on optimizing the parts rather than the whole worked well. In the technological era, American competitive success requires research and teaching that optimizes systems or wholes rather than subsystems or parts.

The Engineering Research Centers, then, have as a basic purpose the triggering of a fundamental change in the culture of engineering. Some have suggested that engineering is entering a period of change similar in its dimensions to the change that occurred at the end of World War II, when engineering became science-based.

This workshop, with its specific focus on information exchange, must therefore take that fundamental cultural change immediately into account. It is not at all clear that the traditional modes of information exchange between universities and industry are appropriate to this changing engineering culture.

Innovative engineering in the technological era involves more than just the transfer of cognitive information. Engineering in the technological era has many of the characteristics of art; it is, however, a unique art form. It is usually done within organizations and groups. These groups, consisting of people with diverse specialized skills, create synthetic products and processes in a manner that is, as yet, little understood. This innovative process requires melding together highly specific and detailed expertise and experience in solving problems that go beyond the capabilities of any one discipline.

The kind of communication to be addressed in this workshop is communication between such groups within the ERCs and similar groups within industry. It is important to emphasize that for the ERCs to be successful there must be information exchange--a two-way discourse.

There are indeed a wide variety of information techniques and mechanisms, ranging from the telephone to traditional publications to computer networks, which are and will be central to successful exchange of information; but it should be clear that if all we do is exercise these mechanisms, the ERCs will not be able to contribute successfully to the nation's economic competitiveness.

Successful information exchange will be a creative activity. It requires contact and opportunity. Therefore, innovation will most likely occur where informal communities are created that tie together interested parties from the universities and from those industries for whom the work of the universities is relevant. As a case in point, consider the speed with which innovative research occurs and is utilized in such areas as health. A similar dynamism has been seen in the past in defense and space technology, and over a longer period of time in agriculture. In each of these instances, there exist communities or sociological systems that keep abreast of what is going on and are stimulated to new creativity through a wide range of continuous and informal communications.

Success appears to be greatest when those in industry and those in universities are plugged into the same wavelength. Success is also greatest when communication occurs among people who know each other, have shared interests, and are able to communicate efficiently in what becomes a shorthand language. The ideal communication system, then, is one in which industry and university people know each other and communication occurs informally. Success is high when these people instinctively telephone each other to seek counsel, advice, and suggestions, and just to investigate or discuss possibilities. All of the evidence suggests that information exchange occurs most successfully when a part of that exchange involves discussions over drinks, "bull sessions" by people with common interests. The goal is to create social systems in which people in universities and people in industry start with the assumption that there are benefits inherent in staying in contact with each other.

There are three types of communication that, ideally, one would like to have flowing from the ERCs to industry. The first is ordered, structured, specific information--the findings of experiments or investigations, the kind of information that is normally published in professional journals or technical reports. The second kind of communication concerns what we may call, for lack of a better label, "technology transfer." Technology transfer differs from specific information in that it is characterized by ideas or concepts for new or improved products or processes. Technology transfer involves the communication of wholes, as opposed to discrete bits of information.

In general, this kind of communication occurs with the movement of people from the universities into industry. Whether it be faculty or students coming from the universities into the industrial context, one is looking for the transfer of wholes rather than parts; and the way that is normally done is to cycle people between the two sectors.

The third kind of communication and information exchange is more elusive, but perhaps in the end more critical. This involves the kind of idea exchange which is likely to occur informally and in unpredictable ways, and which stimulates advanced thinking or creativity on the part of those who are involved. The objective here is to create a university-industry environment that continuously stimulates people to try to push the state of the art, and to think about the future and new possibilities or capabilities.

If one starts from the other direction, what is it that universities should be receiving from industry? It seems to me that industry feedback to the universities ought to have the same three components mentioned above. But in addition there is a need for industry to communicate a picture of what its future needs will be. It is important to emphasize that the Engineering Research Centers are not to be "job shops." Their objective is to do research and turn out students who will be the innovators of new products and processes 10 to 20 years down the road. This suggests the need for industry to be thinking about and communicating to the universities its longer-term problems and needs. Continuing programs which involve advisory committees from industry, seminars which involve industry personnel, and other such interactions, are clearly important. The goal, again, is to create a community made up of the people who are actively and continuously involved in and oriented toward pushing the state of the art. The need is to change the engineering culture.

The preceding discussion is general, and applies to all of the ERCs and all of the industries involved. It is important, however, to be more specific. The particular character of information exchange that occurs will likely vary substantially from one ERC and its interested industrial community to another. That is, communication exchange will vary depending upon the overall research focus of the center. Each of the Centers has been established with a reasonably specific generic set of concerns. The initial Centers have such foci as telecommunications, biotechnology, and intelligent manufacturing. Those generic foci mean that the specific ERCs will relate to different portions of industry. Where the focus of the Center is on new products, as will likely be the case in telecommunications, the nature of information exchange will differ from that in Centers whose focus is on production processes, such as intelligent manufacturing systems.

In preparing for this workshop we concluded that it was useful to try to draw a line between these two general foci. One workshop roundtable will focus on the ERCs that are linked to mature industries, wherein the major concern is likely to be with innovation that leads to incremental improvements in production processes. For example, the auto industry or the farm equipment industry will likely benefit most from research that allows them to increase the flexibility and efficiency of production processes. A second roundtable will focus on the centers concerned with the development of new products.

This distinction is important because, in those industries that are in the process of innovating new products, there is likely to be a substantial in-house R&D capability. Where such an R&D capability exists in industry it is much easier to plug in traditional academic research. Alternatively, in the more traditional production industries research results delivered in the traditional academic format are not likely to be very useful--in some instances, perhaps not even understandable or intelligible to the industry. Manufacturing industries may be able to use the products of the ERCs only if the communication is translated into a form that can be used on the production floor.

It was also decided to focus a third roundtable on cross-disciplinary communications within both the university and industry. If communication is a major issue because of the changing character of engineering research, it should be useful to talk about communication among the various disciplines within the university that will be doing this new kind of synthetic research and teaching, on the one hand, and among the various specialists in industry that will use it, on the other. Academics tend to be provincial. They tend to understand and reward (which is perhaps more important in the context of the university) those people who perform within known disciplinary boundaries.

The key to the success of faculty members in the universities is publication. Cross-disciplinary research poses problems from the standpoint of publication. This kind of research is difficult for universities to evaluate and (therefore) to reward. Further, if information is to be communicated by the university in a form that is usable to industry, and if the universities are to be able to pick up information from industry and use it to stimulate their research, the university must develop the right kinds of information-sending and receiving equipment. For example, it might be necessary to think about creating new journals in which to report the work being done in the Engineering Research Centers. A journal could be not only an important communications medium in its own right; but it might very well also be the vehicle whereby those working in the Centers can report their work and thus be rewarded.

Another issue that was raised, but which was not built directly into the workshop, is the fact that there clearly are important differences between the information exchange requirements of large industries with ERC links and those of small industries with ERC links. The most important point is that small industries frequently have few receptors for research results.

Once again, the goal is to identify specific courses of action that the NSF might encourage the Engineering Research Centers to take as it develops the ERC program. It is to be hoped that the workshop can arrive at something that will be of value to the NSF, and that will contribute to the critically important success of the Engineering Research Centers.

MECHANISMS AND CONDUITS OF INFORMATION FLOW: OPTIONS AND THE NEED TO MAKE CHOICES

A. Michael Noll

INTRODUCTION

An important element in the success of the Engineering Research Centers (ERCs) will be the continuous exchange of information, technology, and ideas among and within the ERCs, and also between the ERCs and industry. Another word for this exchange of information, technology, and ideas is communication. Thus, communication is essential to the success of the ERCs.

Communication is such a common and basic part of most interactions that it is often taken for granted. The concept is also frequently surrounded with a good deal of "motherhood and apple pie." Nevertheless, some substantive, if preliminary, ideas and thoughts can be put forward that are relevant to the nature of the communications situations that will occur within the ERCs and between them and industry.

The first group of thoughts suggests an overall framework for the communications situations that will be encountered between the ERCs and industry, and includes identification of the key players in the process. The second group of thoughts is concerned with the different types of communications media that are available. A third topic to be considered regards the choice of an appropriate medium of communication for different communication situations in general, and for specific kinds of communication among the ERCs and between them and industry. Finally, the uncertainties governing interactions with small businesses, and other unanswered questions will be discussed.

COMMUNICATIONS FRAMEWORK

The communications framework is a two-way flow of information between the ERCs and industry. Exhibit 1 depicts this flow. Within the ERCs, there are a variety of involved people. The first category is faculty, including faculty who are involved primarily with teaching, and also faculty and staff involved primarily with the performance of research. The second category is students, including both undergraduate and graduate students with differing educational and research needs and interests.

Industry consists of large, medium, and small-sized firms. These firms all have differing needs and interests with regard to engineering research and development. More will be said later about the need for characterizing these firms.

The ERCs will generate information that will be disseminated to industry. Much of this information will be based upon the results of research, and will be in printed (paper-based) form. The ERCs will also generate new technologies that will be transferred to industry. This type of technology transfer usually occurs through the transfer of personal experience, and so it is people-based. Students graduated by the universities and hired by industry will commonly be a medium for such transfer.

Communication between the ERCs and industry also flows in the other direction. Industry will need to express its problems and needs to the ERCs to ensure the relevance of the research performed by the ERCs. As Exhibit 2 illustrates, industry will give the ERCs a view of the real world, and the ERCs will give industry new solutions to their problems along with a longer-term perspective. Besides being bi-directional, the communication between the ERCs and industry is also interactive. Communication of a given type does not occur just once; it is a continuous interactive process.

There are a number of mechanisms to ensure and facilitate this communication; some mechanisms are formal and others are informal. In the end, much of the communication will be interpersonal. Communications among people are a key component in the flow of information. There are, in addition, a wide variety of communications media that can be considered for communication between ERCs and industry and also among the ERCs.

EXHIBIT 1 Communication flow.

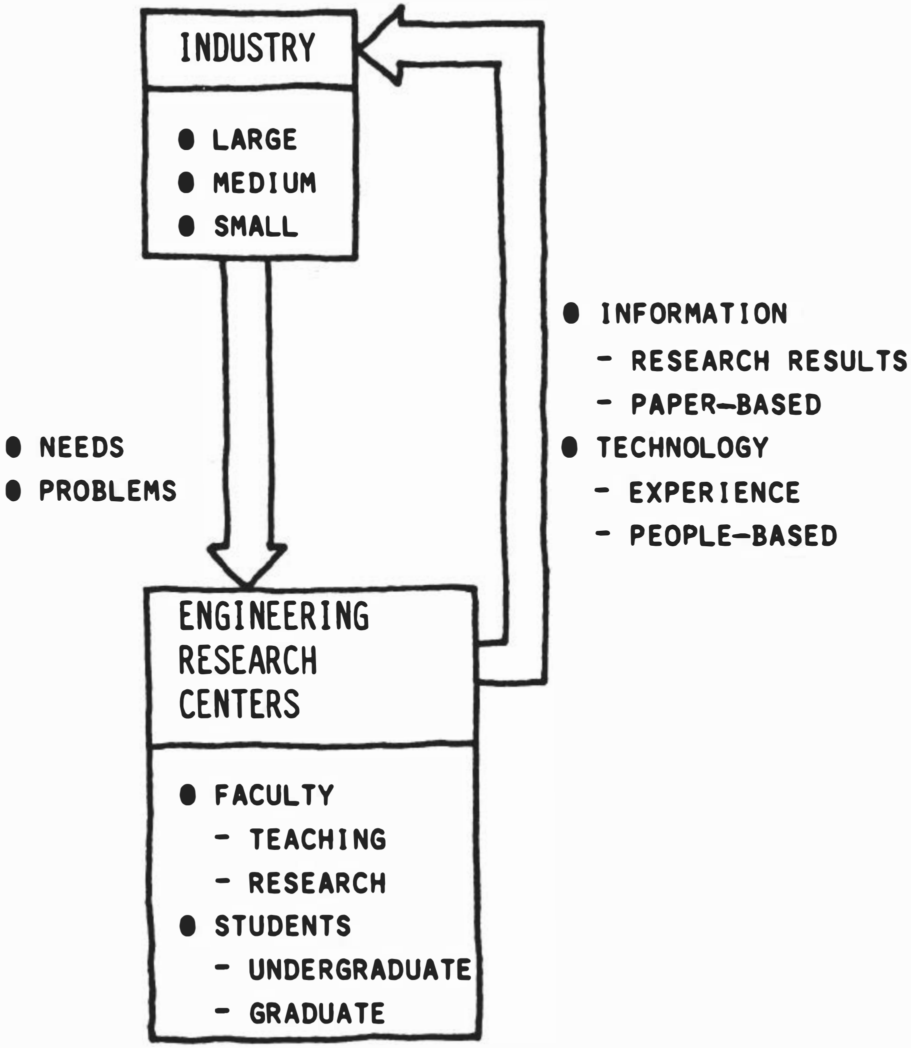
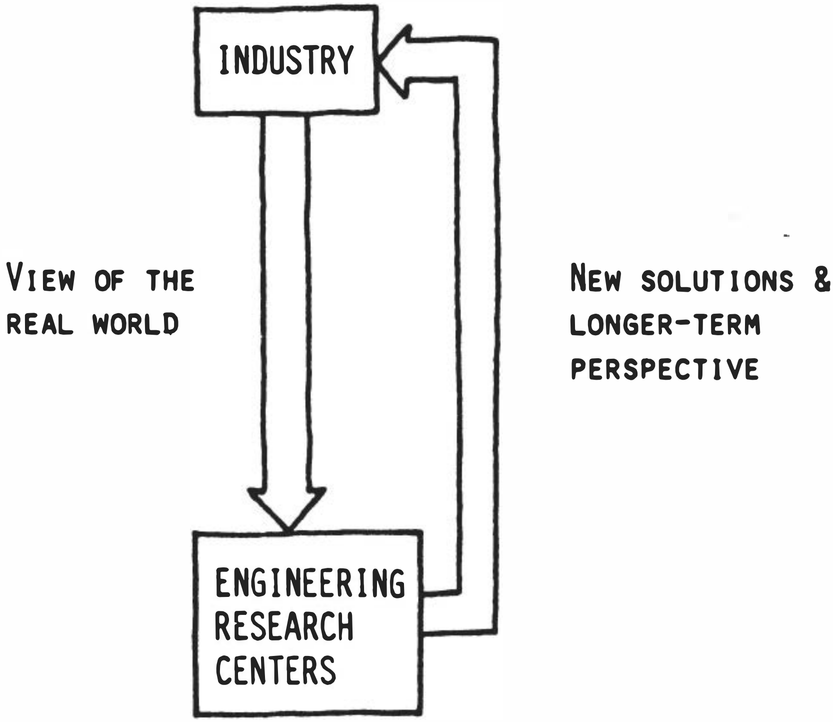


EXHIBIT 2 Communications interdependency.



PROCESS IS . . .

- TWO-WAY
- INTERACTIVE

WITH MECHANISMS THAT ARE . . .

- FORMAL
- INFORMAL

COMMUNICATIONS MEDIA

Exhibit 3 lists some of the communications media that are relevant to the communications situations that will be encountered within and among the ERCs and also between them and industry.

Some of these media are more costly and esoteric than others. For example, the telephone is taken so much for granted that its great effectiveness is often overlooked. Industry people are not accustomed to unanswered telephones; yet many university telephones go unanswered if no one is in the office. Two simple solutions to this perennial problem would be call forwarding to a central location, or the use of a telephone answering machine. A directory of ERC people organized by specialty or area of expertise would facilitate contact by industry for some specific problem. Prerecorded announcements could be used to explain the purpose of the ERC and describe specific projects under way.

MATCHING MEDIA WITH COMMUNICATIONS SITUATIONS

The different communications media listed in Exhibit 3 can be categorized in different ways, and therefore, can be appropriately matched with different communications situations and needs. Exhibit 4 shows some of these categories or dimensions, against which specific media can be ranged. Some media are more formal than others. Some are public or "broadcast" in nature, while others are more appropriate for one-on-one situations. Some media are immediate, while others are more appropriate for delayed communications; some are relatively costly, while others are relatively inexpensive; and some are more appropriate for personal communications, while others are quite impersonal.

Consider teleconferencing as an example of a communications medium. There are two types of teleconferences. One type involves two groups of people in different geographic locations, who conduct a conventional, interactive, two-way meeting over distance through the use of telecommunications technology. A second type of teleconferencing involves a predominantly one-way flow from one location to many other locations in a broadcast (or narrowcast) form of communication.

There are a variety of teleconferencing technologies, differing in cost and capabilities. Audio teleconferenc-

EXHIBIT 3 Communications media.

- Face to face (in person)
  - meetings
  - conferences
  - seminars
  - luncheons
- Paper-based
  - reports
  - newsletters
  - tech briefs
  - published papers
  - popular press
- Electronic mail
  - messages
  - bulletin boards
  - computer conferencing
- Conventional mail (physical delivery)
- Teleconferencing
  - group to group
  - one to many (broadcast/narrowcast)
  - telephone conference bridges
- Recorded media
  - audio cassettes
  - video cassettes
  - video disks (interactive)
- Telephone
  - call forwarding
  - answering machines
  - prerecorded announcements
  - referral guides (by expertise areas)
  - networks

ing is the least expensive. Its elements include the simple speakerphone, portable units, or permanently wired installations. The audio channel can be augmented with a graphics capability: facsimile is one option, and slow-scan video is another. Full-motion video is quite costly for two-way point-to-point teleconferencing, but is appropriate for broadcasting courses and prepared presentations in a closed-circuit television format.

Group-to-group teleconferencing is more appropriate for some types of meetings than for others. Research indicates that recurring, information-exchange types of meetings are very good candidates for teleconferencing. Thus, the information-exchange and coordination meetings among ERCs might be able to use teleconferencing to facilitate communications. A major advantage of teleconferencing is that people who otherwise would not be able to travel can "attend" the meeting.

COMMUNICATIONS AMONG AND WITHIN THE ERCs

Of the preceding choices of communications media, Exhibit 5 summarizes those that can best be applied to different types of communications situations that will be

FORMAL	X_____X_____X_____X_____X	INFORMAL
PERSONAL	X_____X_____X_____X_____X	IMPERSONAL
BROADCAST	X_____X_____X_____X_____X	ONE-ON-ONE
IMMEDIATE	X_____X_____X_____X_____X	DELAYED
COSTLY	X_____X_____X_____X_____X	INEXPENSIVE

EXHIBIT 4 Communications dimensions.

EXHIBIT 5 Media for communicating among and within ERCs.

People-based	Electronic
• meetings, conferences, seminars	• telephone
• faculty and student exchange	- specialty directories
Paper-based	- networks
• annual report	• electronic mail
• exchange of reports, papers, etc.	- messaging
• ERC journal	- bulletin board
	• teleconferencing (group-to-group)
	- audio
	- wired room

encountered among and within the ERCs. The media presented here should not be viewed as all-inclusive; ERCs should be encouraged to experiment with different media for different communications situations.

COMMUNICATION BETWEEN ERCs AND INDUSTRY

A variety of communications media are relevant to the types of communication that will be encountered between the ERCs and industry. These are listed in Exhibit 6.

MARKET SEGMENTATION

Communication between the ERCs and industry is something akin to a marketing effort. Industry can thus be viewed as a customer for work performed by the ERCs. Hence, information about customers is required in order to understand their needs.

Industry can be segmented into large, medium, and small businesses. Large businesses will have their own research laboratories, and will be quite familiar with the nature of interactions with universities. Collegial relationships will already exist between university researchers and their industry colleagues. Professional journals and meetings are one way in which the researchers customarily stay in contact with each other. Student placements and informal visits are other ways. The characteristics of large businesses and the mechanisms

EXHIBIT 6 Media for communication between ERCs and industry.

People-based

- professional societies
- meetings and conferences
- luncheons
- student placements
- courses
  - conventional
  - recorded media

Electronic

- telephone
  - referral directories
  - recorded announcements
- teleconferencing
  - phone-in bridging to meetings

Paper-Based

- annual report
- tech briefs and newsletters
- mass press
  - placed articles
  - interviews

for communications are well understood from past interactions.

Medium-sized businesses have less technical sophistication and are less familiar with universities. However, consulting relationships will have existed with individual faculty members in the past.

Small businesses are numerous, and little is known about them except that their needs are very near-term and product-oriented. Many of them will believe that they have little use for academic engineering research. Generally speaking, they do not read the professional literature and do not have collegial relationships with university faculty.

The usual marketing response when little is known about a customer is to perform market research. From the standpoint of ERCs, then, an appropriate methodology would be to conduct focus-group interviews with selected small businesses. Their specific needs would thus be articulated and appropriate communications channels for reaching them would be identified. Their interactions with trade associations could be explored as a possible communications channel. The types of magazines that they read could also be determined.

CONCLUSION

The concept of ERCs is truly exciting. The ERCs offer a wonderful new opportunity to change the nature of engineering education and to improve the productivity and competitiveness of American industry. However, for the ERCs to be successful they must communicate successfully. But how does one know if the communications have been successful? What measures can be employed? Are there market incentives that can be used as indicators? (For example, should newsletters and reports be sold, so that the value of the information to industry can be ascertained?) Should courses and seminars be sold for similar market-evaluation purposes?

Undoubtedly there are more questions than answers; but answers should be sought. The experimental nature of the ERCs should extend into communications. The existence of many ERCs trying differing approaches to communication in different situations should create a body of knowledge on what succeeds and what fails. Over time, answers will emerge.

INDUSTRY AND INTERDISCIPLINARY TEAMS: EXPERIENCE AND EXPECTATIONS

James F. Lardner

The people who were instrumental in developing recommendations that led to the establishment of the Engineering Research Centers (ERCs) believed that the ERCs would help to achieve several objectives. The first of these was to establish a multidisciplinary university research environment in areas where students are being prepared to work in the manufacturing fields. The second was to conduct engineering research in the field of manufacturing and to codify that research into instructional material to be used by other institutions, and particularly by nonresearch colleges and universities and by industry for training or retraining employees. The third objective was to establish a closer and broader relationship between industry and universities in matters dealing with manufacturing research. The anticipated products of the ERCs--basic engineering research, and graduates conditioned to work in and take advantage of multidisciplinary manufacturing environments--are seen as necessary elements in the drive by American industry to become and remain competitive on a global basis over the long term.

The emphasis on multidisciplinary research contained in the ERC recommendations developed out of a growing recognition that manufacturing in all its aspects is a system--or, perhaps more accurately, a series of systems--and that it must be dealt with as such.

THE SYSTEMS ASPECTS OF MANUFACTURING

This systems concept of manufacturing has created a good deal of confusion in both industry and academe. The confusion results from a fundamental misunderstanding of the term "system" when used in this context. Before we can understand systems aspects of manufacturing, however, it is necessary to understand what modern manufacturing is. The most appropriate--and increasingly accepted--description of manufacturing is that it begins with the product concept and ends with support of the product in the field, and that no single aspect of manufacturing can be treated in isolation from all other aspects, even though manufacturing is incredibly complex in all its details.

If we accept the fact that manufacturing is an activity composed of a very large number of different activities, all of which are inextricably interrelated, and that this interrelation forms a dynamic system, then we have the basis for understanding the systems aspects of manufacturing, and thus for establishing the conditions under which manufacturing research must be conducted.

However, simple recognition that manufacturing is a system--and an incredibly complex one at that--is not enough. It is also necessary to understand what kind of a systems problem manufacturing represents. At today's stage of evolution in manufacturing, there are two distinct but related systems. Each addresses a different aspect of the manufacturing continuum, but the two are totally interdependent. It is this fact that has caused much of the confusion and misunderstanding on the part of theorists and practitioners as they grapple with the problem of trying to transform manufacturing from an art to a science by using a systems approach.

First, a manufacturing organization is clearly a human organization. In the absence of true artificial intelligence or large numbers of integrated expert systems, people working within an intricate organizational structure are the action agents for the creation, transmission, interpretation, derivation, storage, retrieval, evaluation, and modification of the data and information required to plan, manage, and control the material transformation operations. In spite of a growing number and variety of computer-based systems that are being introduced into the data processing activity that support the transformation operations we commonly call manufacturing, that data processing activity is fundamentally a human-based system. It is here that manufacturing research will have the greatest impact on industrial competitiveness, and it is precisely this area in which little research of real or immediate significance has been or is being done.

The material transformation operations themselves are the second major system in manufacturing. Though these operations currently consist of varying mixtures of people and machines, there is a significant and increasing trend toward the elimination of people from the material transformation system. It is in this area that most manufacturing research has been and is being focused.

The fact is that the data processing, human-based system and the material transformation machine-based system are both parts of a single dynamic system. Unfortunately, the amounts of hard knowledge, based on research, available to operate each system are far from equal. The human-based data processing system is woefully behind the machine-based system in terms of available research-based knowledge to support decisions. It is this knowledge deficit that creates the compelling need for the kind of research the ERCs are expected to accomplish.

Current literature dealing with manufacturing suggests that industry, driven by the need to survive, has recognized this knowledge deficit earlier and to a greater degree than has the academic community. I believe that this is indeed the situation. While academia continues to worship at the altar of individual achievement and specialization, manufacturing is moving rapidly toward team effort, integration, and a holistic approach to problem-solving. This is true in the so-called emerging industries as well as in the longer-established, traditional industries. Though there is a difference between the needs and priorities of new, emerging industries and those of industries that have reached at least temporary maturity, in the end the problem is the same.

New industries tend to emphasize new product development and product innovation. The need to be first to the marketplace with a new product is seen as the basis for competitive success. Manufacturing efficiency, unit cost, quality, and serviceability frequently are secondary considerations until the market begins to mature. In this environment, the development of manufacturing processes is generally product-driven and an intimate relationship between product designers and manufacturing engineers is the norm. Speed, responsiveness, and the ability to actually produce the product are paramount, and an intimate multidisciplinary relationship is created. In this environment, the human data processing system is biased toward creating new products and processes, both of which change frequently.

In established industries, on the other hand, truly new and unique products are rare. For companies in these industries price, quality, serviceability, reliability, and function are more important elements of success than novelty. In this environment, the need to integrate the human-based system with the machine-based system is even greater than it is in emerging industries. Attention to detail is important in the production of a successful product; process and product must become two aspects of a single, integrated effort. In industries faced with the challenge of continuously refining established products and processes, an emphasis on the synergy possible through integration of knowledge is fundamental to success. It is here that the multidisciplinary, system-focused environment becomes critical to competitive survival.

ONE COMPANY'S EXPERIENCE

In my company,*, which represents a well-established industry, we are emphasizing the multidisciplinary, systems aspects of manufacturing. We are working with computers and other programmable devices to make the material transformation process more flexible, more precise, more stable, and far less labor-intensive. We are, however, concentrating our principal efforts on the human-based portion of the manufacturing system in order to improve the productivity of our people resources. To accomplish this we have done several things. First, we have formed multidisciplinary groups focused on a single project or problem. We have relieved these people of day-to-day departmental and administrative responsibilities and have made their participation in the group, when and where required, a primary responsibility. Further, we have charged the members of these groups collectively and as individuals with responsibility for the success or failure of the project to which they have been assigned. To ensure a "real-world" environment, these groups have been given as much information, confidential or otherwise, about the project and that part of the business affected by the project as the senior management of the division has available.

*Mr. Lardner is Vice-President, Component Group, of Deere and Co., a manufacturer of agricultural machinery and equipment.

The results have been both surprising and gratifying--even exciting! Almost without exception the members of these groups--both long-term employees and younger, less experienced people--have participated enthusiastically and effectively. No one who has been involved in one of these projects wants to go back to the traditional method of operation, which depended on coordinating the sequential efforts of many separate functional organizations toward a common goal.

Our people are eloquent about the improvement in the workplace environment, the reduction of frustration, and the extension of their individual capabilities that are made possible by having people from many disciplines immediately available and participating. Almost all participants speak of greater opportunity for professional growth. From a competitive standpoint, we find we can compress project schedules, spend fewer engineering dollars, reduce capital investment, improve quality, and meet cost targets. We have no intention of ever reverting to the old way of doing things.

There are, however, still plenty of problems. While we have improved the functioning of the human-based system by changing the organizational structure, we have not improved the knowledge base available for decision making. To cite only a few examples: What are the essential characteristics of manufacturability, and how do you describe them? How can a designer be sure he is not unnecessarily increasing the proliferation of similar parts within a manufacturing system, thus driving total overhead costs up? How can manufacturing engineers determine what level of programmable flexibility is appropriate for a given manufacturing task? Where are major investments justified to reduce production lot sizes? What are the most practical means of evaluating the effective use of resources in developing factory layouts, selecting equipment, and even in designing products? There is an additional set of questions which deal with the human-system/machine-system interface. There is also the exciting potential represented by expert systems integrated with machine networks, which would make an entire factory function as a flexible manufacturing system.

All of these areas and many more are worthy of research by highly competent, well-trained professionals; and the hard knowledge resulting from such research efforts, intelligently applied, could be a major factor in the survival of American industry in a globally competitive world.

ERCS AND INDUSTRY

To achieve the objectives and results we seek, we must structure the ERC/industry relationships to ensure that reality is brought to the campus; that industry recognizes and understands what universities can and cannot do; that there is a freer flow of information and people between industry and academia; that both professors and students recognize what a successful competitive, industrial environment is like; that the full importance of the systems problem is recognized; and, finally, that all involved can experience the magic of successful execution of a complex manufacturing project in as realistic an environment as possible.