Education and Utilization of Engineers: Recommendations for a Study (1981)

Pages
41

Size
8.5 x 10

ISBN
0309330971

Committee on the Education and Utilization of the Engineer; Assembly of Engineering; National Research Council

The Education and Utilization of Engineers:

Recommendations for a Study

A report by the
Committee on the Education and Utilization of the Engineer
Assembly of Engineering
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1981

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the project were chosen for their special competences and with regard for appropriate balance.

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

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This study was supported under Contract No. EAS-8107881 between the National Science Foundation and the National Academy of Sciences, and Contract No. B1981-16 between the Alfred P. Sloan Foundation and the National Academy of Sciences.

PREFACE

Late in 1980, the National Science Foundation requested that the Assembly of Engineering, National Research Council, conduct a multiphase study of the professional education and utilization of engineers in the United States during the remainder of the century. The first phase would be devoted to the identification of issues related to the status, needs, and opportunities for the profession, to the planning and structuring of an appropriate study effort, and to identifying some desirable kinds of participants for the study. The study was to be Phase II of the activity, and a short-term Phase III effort would disseminate the study results. Phases II and III were to be contingent upon the satisfactory completion of the Phase I planning. Moreover, while Phase I was to be wholly supported by the NSF, it was expected that Phases II and III would involve joint sponsorship with the Department of Defense, National Aeronautics and Space Administration, Department of Energy, and possibly other federal agencies.

In response to the NSF request, early in 1981 the Assembly established the Committee on Education and Utilization of the Engineer The committee held four meetings at approximately monthly intervals for the purpose of developing the plan and recommendations contained in this report. Early in its deliberations, the committee established a task-group to prepare a potential outline for a Phase II study report and six additional task groups to develop topics for study in the areas of:

- The current status of the engineering infrastructure
- The current status of engineering manpower
- The current manpower adequacy
- Future demands on engineers

- The response adequacy of the infrastructure
- Changes needed in the infrastructure

This report presents the findings and recommendations of the committee, based on the task group activities, with regard to a desirable content, methodology, and participants in a two-year Phase II study. Within the time available, the committee was able to identify a large range of topics needing study, but not to assign priorities for their address. While intellectually unsatisfying, such an omission was not considered critical for several reasons. First, the resources to be made available in support of a Phase II study were not known to the present committee. Second, the Phase II study would be conducted by a substantially different committee membership. Since Phase II would have to be cut to fit the financial and intellectual cloth yet to be woven, it was thought more important to procede directly into the Phase II activity rather than to take the time to polish the details of a necessarily indeterminate study position by the Phase I committee.

COMMITTEE ON EDUCATION AND UTILIZATION OF THE ENGINEER

Edgar M. Cortright, *Chairman,* Lockheed California Company.

George S. Ansell, Rensselaer Polytechnic Institute

Daniel C. Drucker, University of Illinois at Urbana-Champaign

Norman G. Einspruch, University of Miami

Robert A. Frosch, American Association of Engineering Societies

Aaron J. Gellman, Gellman Research Associates

Norman A. Gjostein, Ford Motor Company

Kenneth E. Haughton, IBM Corporation

Terence Kett, Exxon Research & Engineering Company

Morris H. Morgan, General Electric Research and Development Center

Harold W. Paxton, U.S. Steel Corporation

William J. Perry, Hambrecht & Quist (Investment Banker)

Gerard A. Rohlich, The University of Texas at Austin

Bernard I. Spinrad, Oregon State University

Seth H. Washburn, Bell Laboratories

Sheila E. Widnall, Massachusetts Institute of Technology

CONSULTANT

F. Karl Willenbrock, Southern Methodist University

SUMMARY

Although the engineering profession has served the United States well thus far in the 20th century, there are widespread perceptions of problems that cast doubts about the adequacy of the nation's future engineering capabilities. Many persons, particularly those involved in engineering education, view some of the problems as having reached major proportions, therefore such concerns as those relating to the retention of adequate engineering faculties or the updating of collegiate instructional equipment require immediate attention by appropriate groups. Beyond this, however, a need exists for a coordinated, comprehensive study of the outlook for the whole engineering community of educators, users, and support groups over the next twenty years to establish the dimensions of the problems that may have such important implications as to require major efforts for resolution, and those problems that can be resolved with less drastic actions.

It is recommended that such a comprehensive study be conducted within the next two years.

A study of such limited duration will necessarily be limited to a general consideration of the engineering infrastructure, but it should be organized so that later, supplemental analyses of specific engineering fields and disciplines can be undertaken through an extension of the study protocols.

To be received as balanced, reasoned, and objective by engineers and non-engineers alike, it will be important that insofar as possible within the time limits, the study

- o Define the engineering infrastructure and interrelations among the main elements;
- o Determine the current status of the principal elements and their recent historical relationships to major economic, political, and technological events;

- Determine the decision-making factors for the main elements and identify the typical response modes;
- Project plausible future kinds of events that might drive the need for major decisions in the engineering infrastructure; and
- Recommend policies and programs that will be needed to make the infrastructure elements capable of meeting future national demands and propose priorities for the various actions.

The study should indentify optional actions, wherever possible, including those that might be taken by private industry or academic institutions, as well as those that are clearly appropriate for government actions.

The proposed study might properly be viewed as a precursor of a continuing evaluation of the engineering community. Within a two-year study it will be difficult to define, describe, analyze, and diagnose all of the problems of a loosely defined engineering community of more than one million individuals, and to prescribe needed remedial actions. If, however, a relatively clear consensus can be reached among the leaders of the community on the problems and potential solutions, so that national policy and program guidance can be developed to ensure the future engineering strength of the nation, the effort will have been worthwhile.

I

INTRODUCTION

The 20th century has been a period of impressive and unprecedented technological growth that has revolutionized the lives of most of the world's population. The United States has been a leader in that technological revolution, and its engineering profession has been a principal factor in establishing such supremacy. In the process, the engineering profession has been subject to all the pressures that arise from new technologies, new engineering tools, and new expectations of continuing innovation and improved performance, safety, and reliability.

We are now entering a period that some characterize as an era of increasingly scarce human and physical resources. At the same time, scientific discoveries are proliferating, and there is every reason to believe that the pace of technological transformations will increase for the remainder of this century. There is increasing concern by some that the engineering community may not be able to respond adequately to the tasks ahead. Many persons are troubled by perceptions that the U.S. is not developing or using its full intellectual potential, that it is not capitalizing on its available technology, and that it is losing its technological leadership. Almost all of the persons directly involved with engineering schools are convinced that there are already severe problems in engineering education that if left unchecked will lead to a progressive de-deterioration of the technical colleges and universities of crises proportions*.

*A number of groups have addressed various aspects of engineering education concerns over the past year or so. Appendix A outlines the principal efforts and the nature of their findings.

Perceptions such as these would seem to signal serious future problems for the nation, and those that are of clear and present concern, such as a number of issues dealing with the adequacy of engineering school faculties, or with the obsolescence of school equipment for training engineers, need to receive immediate *ad hoc* attention. Unfortunately, the evidence required to verify the accuracy, extent, and import of some of the perceived problems is difficult to marshall. Data on engineering manpower availability and deployment, for instance, have many quantitative and qualitative deficiencies, and their interpretation is complicated. Furthermore, several of the important aspects of the perceived problems are partly or wholly matters of judgment that do not lend themselves to quantifiable analyses.

This report presents the findings of an effort to define the approach for a longer-term, comprehensive study that needs to be conducted to determine the present and projected viability of the engineering profession in the United States, vis-a-vis its opportunities and challenges. This report marks the end of Phase I; Phase II, accordingly, is the comprehensive study that would serve as a basis for the development of coherent national policies and programs to assure adequate numbers of engineers and their appropriate education and utilization for the rest of this century. Such a study should seek to develop specific, realistic options for the public, private, and academic sectors of society, and to recommend priorities for possible actions.

To be most useful, the report resulting from the proposed study will need to be directed to the engineering profession, the public they serve, and the youth from which their ranks will have to be replenished, in addition to all governmental, academic, and industrial leaders who will be in positions to advocate, select, or implement particular options. The latter groups include:

- The principal employers of engineers--governmental and private;
- State and local governmental officials responsible for the educational and motivational preparation of potential engineering students;
- Governmental officials responsible for the support of engineering schools;
- Federal executive and legislative leaders responsible for authorizing or funding educational support and university research programs;

- Administrators in the engineering schools, and the universities of which they are a part, as well as the faculties, accreditation bodies, and foundations involved in engineering education;

- Executives in industrial companies involved in engineering education through grants, scholarships, sponsored research programs, cooperative training programs, etc.;

- Societies and academies that represent the technical and professional interests of engineers.

There have been numerous studies of engineering which directly relate to the proposed study. These prior studies, together with current perceptions of knowledgeable educators, managers, and engineers, would probably suffice to identify many--if not most--of the problems within the engineering community and to suggest their possible solutions. However persuasive such findings might be to the engineering community, they are not likely to enlist the critical support and action of other decision makers. Consequently, to be effective, the findings should contain an objective and balanced set of conclusions, options, and recommendations based on a more reliable data base than has been available in the past and on analyses that have also been lacking in the past.

To attempt to define, describe, analyze, collate, diagnose, inform, and mobilize support for a loosely defined engineering community of more than a million individuals in the United States is a task that may not be possible to accomplish with precision and within a reasonable time period. Therefore, the Phase II study outlined herein may become only the first step in a continuing activity. If, however, a relatively clear consensus on the problems and their potential solutions can be achieved, so that broad policy and program guidance can be offered to ensure the future engineering strength the nation is certain to need, the effort will have been worthwhile.

II

THE PROPOSED STUDY

As a guide to its consideration of a possible study, the committee prepared a suggested outline for a Phase II report, the main elements of which are presented in Appendix B. It is to be expected that the actual Phase II report will differ from this outline because of the insights and emphases of the study group. The outline is only intended to provide a focus for appropriate study topics. For example, to write the report suggested by the outline, it will be necessary for the Phase II study to address such basic questions as:

What is the "engineering community" and the infrastructure through which it operates?

- What are its principal elements?
- How does the system operate, in general?
- How has it evolved?
- What has been its importance to our society?
- What is its importance to our future?

What is the current state of the engineering infrastructure?

- What is the engineering population by subdiscipline and by function?
- What are our educational and training facilities?
- How are engineers used? Where?
- How effective is our present system in terms of meeting engineering needs?
- What are the shortcomings?

How does the engineering infrastructure function in a dynamic sense?

- How do the elements respond to problems?
- What are the control mechanisms?
- What are the time-constants?

What might the rest of this century require from our engineering infrastructure?

- What are the potential future drivers of engineering?
  (e.g., national programs, new technologies, etc.)
- What kinds of demands might be placed on the infrastructure elements?
- How do we assess the ability of the infrastructure to respond?

What must we do as a nation to ensure that the engineering infrastructure will be capable of meeting our potential needs?

- For numbers of engineers and requisite skills?
- For problem-solving versatility?
- For quick responses to opportunities?
- For anticipating and supplying developing needs?

What are the options and their probable consequences?

What recommendations can be made to our leadership in government, universities, and industry?

It is clear that the engineering community exists and functions as an integral part of society. Engineering goals and directions are intertwined with and reflect societal goals. It is equally clear that policy and program requirements to assure adequacy of the engineering profession for its future societal role require broad societal consensus--a consensus based upon knowledge and understanding of engineering and its complex interrelationships with national needs and goals, human and physical resources, etc.

These questions and considerations arrayed in the outline can be grouped into clusters of topics for in-depth study. Many of the topics are related, and their study will need to be time-phased for most efficient progress. Some, however, can be examined independently.

THE ENGINEERING INFRASTRUCTURE

In many respects, the key to a comprehensive understanding and analysis of the strengths and weaknesses of the engineering profession lies in the clarity with which the engineering infrastructure can be discerned and described. Hence, the description of the infrastructure should be the first order of business for the Phase II study.

The infrastructure is the total complex of institutional system elements that selects, trains, employs, supports, and uses engineers and their services. Over a career cycle, engineers as a class generally follow a somewhat predictable path through the infrastructure, but individuals may enter and leave freely, depending upon competing incentives and opportunities and often at some cost to society.

The systems that comprise the infrastructure may be grouped into several major categories, according to the functions that they serve along the career path:

- Educational systems
  - Precollegiate
  - Undergraduate engineering colleges
  - Graduate engineering universities
  - Technical institutes
  - Nonacademic facilities for continuing education
- Employer community
  - Self-employed
  - Private sector
  - Local, state, and federal government
  - Educational institutions
- Post-entry support groups
  - Technical societies
  - Professional societies
  - Academies
- Public at large
  - Media
  - Advisors
  - Friends, relatives, acquaintances

In order to study the expected reactions of the engineering system elements to any problems or proposed changes, it will be necessary to describe the mutual interactions of the elements. An orderly representation, or model, of the infrastructure will aid in the description, and this committee strongly urges the development of such a model early in any comprehensive study. Figure 1 shows a simplified flow model of the sort the committee considers desirable.

In principle, a model such as that in Figure 1 could be used, if properly refined and expanded, as a dynamic flow model to examine the detailed flows, reservoirs, and capacities of the engineering system over time. The significance of such numbers on a highly aggregated

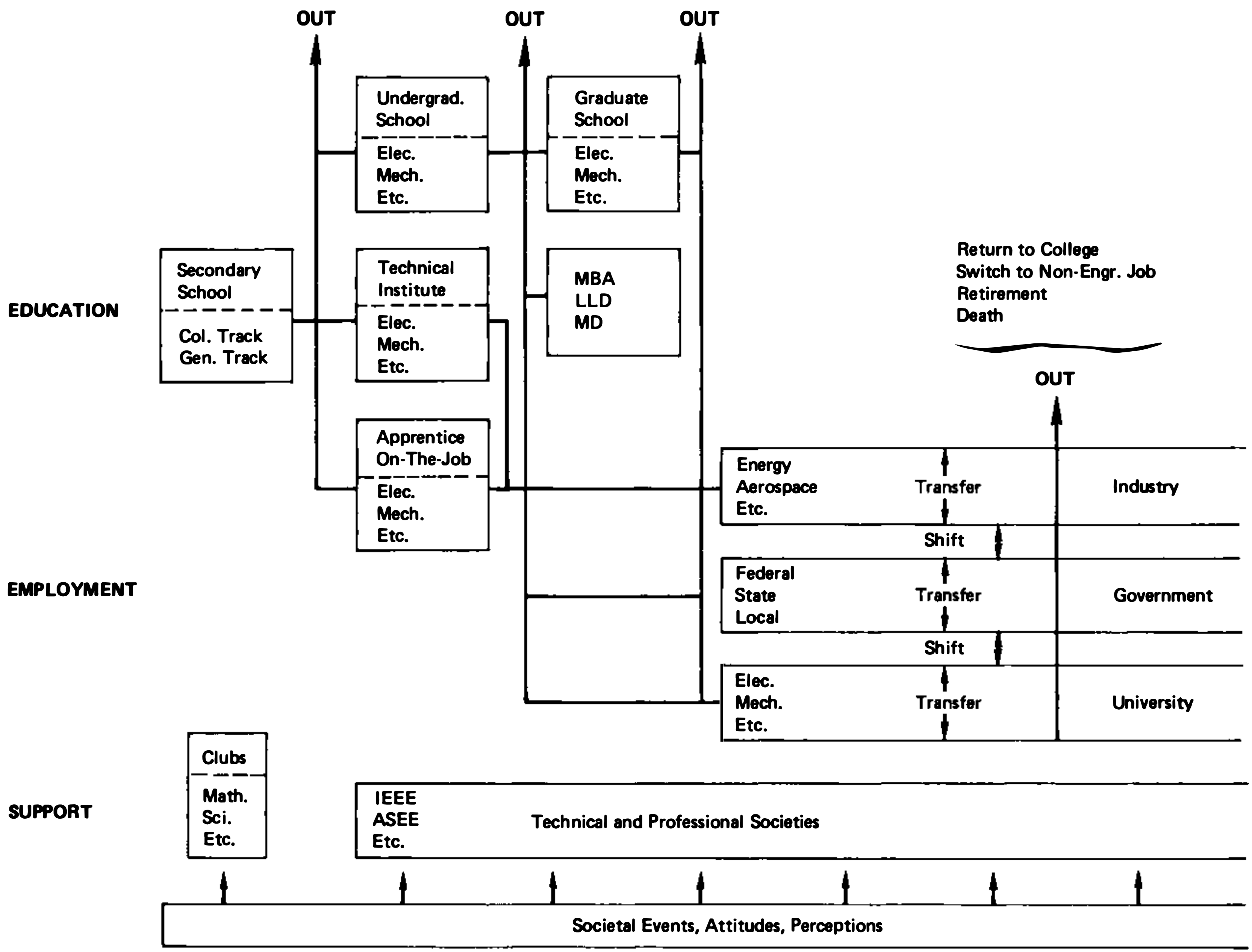

Figure 1: Simplified Model of the Engineering Infrastructure.

scale is doubtful, however, and unambiguous statistics at a more detailed level are lacking. Thus, it is not anticipated that an infrastructure model can be exercised to give meaningful quantitative flow reactions. However, it may be possible to discern from the model, in qualitative terms, some near-term response trends.

Judging the infrastructure needs in response to changes over the long term will require judgements of a more sensitive kind. For example, the use of computers and microelectronic control circuitry in design and manufacturing presages major changes in engineering as well as manufacturing productivity. Any forecast of engineering manpower requirements will have to take this into account by projecting both the penetration of computer-aided design and manufacturing into appropriate industries and the resulting effects on the demand for number and type of engineers in those industries. The explosive technological developments of the recent past, and those that seem likely in the future, should provide ample warning against unduly static projections of future requirement trends in terms of numbers, fields, or educational levels.

HISTORY AND STATUS OF THE INFRASTRUCTURE

Once the engineering infrastructure is defined, it will be necessary to understand the present status of the major elements as a background for the analysis of necessary or desirable future changes to the engineering system. In assessing the future capacity of the infrastructure to adapt to changing conditions, it would be helpful to have an historical perspective on past accommodations to change. Thus, the history and the present status of the infrastructure will need to be examined in consistent terms.

Landmark events in the recent history of engineering need to be studied from the viewpoint of the impacts that these imposed on the engineering system and the responses of the system elements. An examination of the last 50-60 years, for instance, should provide some valuable insights on the system's responses to the impacts of the great depression, World War II, the post-war boom, the space program, and the advent of computers and solid-state electronics on the changing demands for different types of engineers. What were the impacts of such great civil engineering programs as the interstate highway system? Or the nuclear power program? How did the infrastructure respond to the major program fluctuations in the aerospace industries? Or energy shortages or requirements for environmental protection?

Any historical view of the engineering field would need to consider the gradual and subtle changes that flow from new scientific discoveries and their transformations into engineering tools and technologies in various industrial sectors. Such a view should also include the development of new engineering specialties, revisions in educational curricula, organization of new technical societies, and other changes with long-term implications for the profession.

The changes need to be examined in the light of industrial developments that trigger events and trends in engineering, bearing in mind the individual and organizational decisions involved in the changes. The historical examination should be correlated with a parallel analysis of the current status of the engineering system in order to give a sense of the condition of the engineering infrastructure today, how this has evolved, and how economic, political, and technological forces and decisions have affected or directed that evolution.

Engineering Workforce: In addition to examining the principal infrastructure institutional elements, the study will need to assess the changes in engineering human resources. The history and current status of engineers in the workforce needs to be analyzed in terms of such obvious categories as ages, educational sources and levels, technical disciplines, etc. Several sources of current and historical data are the Engineering Manpower Commission, the National Science Foundation, the Bureau of Labor Statistics, and the National Center for Education Statistics. These sources have been valuable in establishing a general profile of the engineering workforce and engineering employment patterns. However, much more remains to be done in this area. In some instances the data are at variance, or the data are inappropriately aggregated or inadequately classified. Much more information is needed on what engineers actually do, on understanding the adequacy of engineering education, on the quality of engineers in the work place, and on understanding occupational mobility in terms of the flexibility of the engineering labor force to fill field-specific shortages. It will be necessary, therefore, to do a comparative analysis of the data bases, to identify any differences and their causes, and to determine how improved collection methodologies and classificaton schemes may provide the needed information. Such an effort should be based on a consistent definition of engineers in terms of qualifications and functions, and on the development of differentiating classifications amongst engineers, technologists, and technicians employed in the same fields. After such a study, one important outcome could be the identification and designation of the best available data base for maintaining a historical record. Such a study could also afford an opportunity to mobilize the available resources, which are now being used in a scattered fashion, to ensure that the principal sets of statistics are at least coherent, if not fully coordinated.

If possible, the workforce data should be collected in a manner that will provide information on the various flow processes described by the infrastructure model. An important aspect of this approach might be the use of engineering manpower models. Much progress has been made in this area in recent years by C.B. Freeman at Harvard, F. Landis at the University of Wisconsin-Milwaukee, and M. Sirbu at M.I.T. These models have been helpful, for example, in identifying the role of R&D expenditures and salaries in alternative professions on engineering employment demand. In the Phase II study, manpower models could be very useful tools, and support should be given to improving their forecasting capabilities.

Any study of the engineering workforce needs to go beyond mere inventory questions, important though they may be, to an examination of the current adequacy of the manpower mix. Important supply and demand trends in significant industries and in critical engineering disciplines should be investigated. For instance, current manpower shortages in certain industries should be investigated to determine their causes and their implications for the overall profession.

Moreover, there needs to be an assessment of the current adequacy of both the quantities and qualities of engineering man-manpower. Of these, the quantitative aspects will be easier to evaluate. The measures of the adequacy of manpower quality will, of necessity, tend to be qualitative. Possible measures might include comparisons of today's engineers with engineers at some earlier period or with engineers in other developed countries. Evaluations of current engineers might also be made by examining perceived engineering needs in comparison with current engineering capabilities, or by looking at the quality of goods, services, and technologies in comparison with desired quality levels. Surveys to assess quality might include the training and educational programs offered by industry in response to perceived needs, performance appraisals, engineer turnover rates, and profile characteristics of both successful and unsuccessful engineers. Such information might be obtained from in-depth surveys or visits with representative companies in various industries.

Engineering Education: Obviously, the educational system that trains the nation's engineers is a key element in the engineering infrastructure. We need to have a better understanding of that system. Have universities been able to keep pace with rapid developments in technology by upgrading their curricula and staying in the forefront with their research programs? As in the case of the analysis of the engineering workforce, much of the needed information is in the nature of an historical inventory. What are the accredited departments? How have the schools and departments changed with time and events? How inadequate are university investments in plant and equipment? What has been the history of engineering school capacities as measured by enrollments and graduation rates? What is the corresponding picture in the technical schools and technology institutes which train engineering technicians and technologists but do not offer engineering degrees?

Another important educational subsystem provides continuing education to the practicing engineer. What is known about the extent and effectiveness of such activities? To what extent are the accredited engineering schools involved in formal training programs on and off campus? What do industry and the government do to make job-related technical training available to their employees? To what extent have the technical societies aided their professional members in maintaining and enhancing their engineering skills in times of expanding and changing technologies?

No inventory of educational capacities would be complete without some measure of the pre-engineering educational infrastructure What has happened, over time, to the number and quality of secondary school graduates who are academically qualified to enroll in accredited engineering schools? To what extent have the able students actually enrolled in engineering courses? How have they fared in their progress toward engineering degrees? Can the data be related in any meaningful way to primary and secondary school academic requirements and curricula?

Engineering Users: To complete the inventory of the infrastructure, it will be essential to have a coherent, credible understanding of the areas and ways in which practicing engineers are employed, and of how employment patterns have varied with time. Some of this information can be gleaned from the NSF and EMC studies, particularly with regard to areas of employment--self, governmental, private sector, and academic. More information is needed, however, on expected educational levels, on how engineers are actually used, on the relationship between engineering classifications used by industry and the traditional classifications by earned degree, on career mobility, on the quality of engineers, and on the impact of new engineering tools on careers.

This committee is particularly concerned with the very broad connotations of the descriptor "engineer." There are many levels of engineering and it will be considered essential for the Phase II study to characterize the various engineering occupations to determine the generic similarities and differences. Unless this is done, it will be difficult to discuss the future quantitative and qualitative manpower utilization problems in engineering in a really meaningful way.

INFRASTRUCTURE BEHAVIOR

The identification of substantive actions that might be taken to correct or improve the elements of the engineering system will be expedited and clarified if the ways that these elements respond to external factors is understood. Therefore, in addition to describing the main elements of the engineering infrastructure, their present status, and their historical background, the Phase II study should examine how the major elements have responded to pressures for change and the constancy and predictability of the responses, if any. Such response characteristics should be examined in terms of the kinds of decisions that are made in response to external factors, the issues that the decisions confront, and the patterns of response that emerge.

In analyzing these adaptive behaviors, it will be important to determine the time scales associated with the typical responses and the long term effects of the behavior. It may be desirable in the future to shorten response time; thus the costs and benefits of changes in the responses will need to be examined.

The various parts of the infrastructure and the individuals within it have a variety of adaptive behaviors that can influence the health and vitality of industries, universities, and society as a whole. The principal participants in the system are individual students and engineers, and the primary institutions are universities, industries, and governments.

Individual Responses

Individuals must make a succession of career choices in response to the following kinds of decision drivers (in no order of rank):

- Perceived personal satisfaction;
- Relative economic rewards;
- Perceived autonomy;
- Intellectual excitement;
- Perceived security and stability;
- Perceived social status, social utility, and contribution to society and the community;
- Knowledge and exposure.

Students have to make a number of career choices with regard to engineering. Should they take engineering or some other college degree? If engineering, what should be the field of specialization? When the B.S. degree, is obtained, should they enter the workforce? Take an advanced engineering degree? Take an advanced degree in some other field (MBA, MD, etc)?

The issues to be studied with regard to these decisions include the impacts of primary and secondary school mathematics and science preparation, the impacts of interactions with practicing engineers, and the response to the personal decision drivers listed above. There should be an attempt to understand why so few women and members of minority groups elect engineering careers, and why there is an increasing appeal for foreign students to take advanced engineering degrees, but a reduced appeal for U.S. citizens?

The practicing engineer must make periodic choices about his career. Should he or she change employers within a field? Should he or she change fields? Continue his formal technical education? Early in his career? At mid-career? Should he or she opt for early retirement and a second career? Each such decision affects the engineer's availability to the profession.

Faculty members who have selected teaching and research as their engineering role, have their own special set of behavioral responses to their own career decision drivers. Typical responses include leaving teaching, changing schools, increasing consulting activities, forming small companies, organizing new projects or new fields, or taking temporary leaves of absence to work in the government or industry.

Institutional Responses

Institutions also must choose periodically from among management options. Some of the drivers that might necessitate such choices are the following:

- New technologies that become teachable, clearly recognizable, and rewardable;
- Competition for survival and growth;
- Cost and efficiency of operations; and
- Political actions.

Colleges and Universities and their constituent departments must make successive decisions about the kind of engineering education they offer. In making such decisions, they may find it appropriate to change or create engineering departments, to change the relative emphases of basic science and applied engineering instruction, to emphasize research, to expand or contract faculty sizes, to strengthen or weaken faculty qualifications, to encourage faculty interactions with industry and government, to expand or restrict overall enrollments, to encourage or limit admission of foreign students, or to seek outside support for research and education.

Industries, in dealing with technological developments, business competition, and economic conditions, make frequent decisions about expanding (or contracting) their engineering workforces. They may, for instance, adjust beginners salaries to entice holders of B.S. and advanced degrees and, sometimes, faculty members to enter their employment. They may upgrade technicians to engineering classifications or use scientists in engineering roles. To upgrade and strengthen employees, they may support the self-improvement of engineering employees, or sponsor in-house or off-site continuing education and reeducation courses for mid-career employees.

It would appear that many industries rely heavily on free market mechanisms in adjusting the makeup and size of their engineering workforces in response to changing needs. They depend on their organizational capabilities to identify and acquire talent on an "as-needed" basis from the national reservoir of engineers on the assumption that adequate reservoir resources exist. This approach needs to be examined for effectiveness and dependability under various future conditions.

Government agencies can influence the infrastructure far beyond the direct employment of engineers. Federal programs in defense, space, energy, etc., exert great quantitative and qualitative demands on the engineering system. Government R&D programs are the predominant sources of engineering research support for university programs. Government programs in support of education (both teaching and equipment) can affect all levels of education. Faculty exchange programs and postdoctoral programs at government laboratories can stimulate and strengthen the faculty. Graduate engineering programs are affected in a major way by the availability of governmentally sponsored university research and graduate fellowship programs. In a less direct way, governmental tax policies influence the levels and kinds of educational support forthcoming from individuals and companies, as well as the level of R&D sponsored by private industry.

The dominant government role in support of university R&D has another, more subtle, impact that warrants examination. It is becoming increasingly difficult to get funding for a research proposal to the government; consequently more and more faculty effort is being expended on "grantsmanship" activities, rather than on teaching or research. This has not gone unnoticed by students and may serve to turn them away from consideration of engineering faculty roles for themselves.

Other Responses

The technical societies, professional societies, and academies have a more indirect effect. They work collectively and influence the engineering system on a longer time scale than do either the schools or the employers. Their adaptive behaviors are directed to the support of the profession and to individuals within it. Each serves a different individual function, but collectively these organizations affect the infrastructure by continuously redefining engineering specialities, maintaining engineering standards, updating and changing accreditation standards, providing communication channels through journals and meetings, conducting studies in areas of disciplinary interest, and arranging and conducting education programs.

In the study of response characteristics of the several system elements, it will be important to ascertain the extent, if any, to which specific responses can be anticipated and guided by specific stimuli or sets of stimuli. To the extent that such cause-and-effect relationships cannot be established, the efficacy of actions proposed to correct known or anticipated system deficiencies will remain conjectural.

FUTURE DEMANDS ON ENGINEERING

Although the past and the present are important elements in understanding the engineering infrastructure, the real concern lies with the future suitability of the systems. To anticipate the problems that might limit the future capability of the engineering infrastructure to respond to changes, it will be necessary to project and examine a number of possible situations that could cause stress to the system's elements. Such situations may be grouped into two classes. First, there are combinations of circumstances with relatively short-term impacts on a few system elements. Second, there are longer term scenarios that could result in more gradual but more lasting impacts on the infrastructure and might require more basic and far-reaching system changes for their satisfactory solution.

Short-term Stresses

Changes in established methods always induce stresses in the associated working structures. With the rapid changes in technology, business, and social expectations in this country, it is not surprising that the engineering community is frequently beset by localized, short-term problems that can have intense impacts on affected system elements and on their responses. While it is unlikely that alterations in the infrastructure can anticipate and prevent the future occurrence of such short-term system drivers, a better understanding of their characteristics might enable some common system corrections to be identified which could ease adverse impacts in the future.

Several categories of short-term problems warrant examination. Because of the specific events and circumstances that contribute to each such occurrence, the committee suggests that rather than hypothesizing problems for evaluation in Phase II, known problems from the recent past should be selected as representative case studies. Although anecdotal evidence abounds about such problems, it will be necessary to examine each selected case in enough detail to establish a factual, credible understanding of the cause-and-effect relationships. Categories that should be investigated include:

- o Industry-wide shortages of engineering manpower (e.g., integrated circuit design);
- o Industry-wide surpluses of engineering manpower (e.g., aerospace in the early 70's);
- o Fields on hold (e.g., nuclear power system design); and
- o Retooling for major productivity changes; (e.g., as in the auto industry).

Long-term Stresses

There are a number of plausible future circumstances in which one or more of the major elements of the engineering infrastructure might be stressed to the point of failure unless extensive and relatively permanent changes are made. The committee recommends that illustrative scenarios be developed for such cases to enable the potential stress points to be identified. The extent to which common problem areas are discerned through such analyses should strongly influence the nature and priority of future policy and program recommendations.

At least four classes of major engineering driving forces can be visualized:

- o The national adoption of one or more major Federal programs with high scientific and technological content;
- o The emergence of new technologies with benefits that warrant rapid introduction into commerce;
- o The coalescence of social expectations into mandates for extensive changes with technological immplications; and
- o International competition.

A number of broad topics should be investigated to determine the potential impacts of future events on the various elements of the engineering infrastructure. Plausible illustrative scenarios should be developed in enough detail to show the manpower, educational, and job-performance implications of the topic. Enough topics should be investigated to establish whether a reasonably broad range of future scenarios produce common or topic-specific stimuli to the engineering system*.

*The Committee was able to quickly develop a representative list of potential topics, as discussed in Appendix C.

For example, certain long-term programs, such as national decisions to develop and deploy certain types of defense systems or advanced energy systems, require fundamentally different types of engineering mobilizations than do most industrial or consumer-goods developments. The magnitude and complexity of the effort may require the parallel development of new infrastructure relationships. One of the characteristic impacts on requirements for engineers is the long period of sophisticated R&D in which great demands are made on graduate-schooled engineers and scientists, with a blurring of the normal distinctions between science and engineering in the drive to create, analyze, and use new and novel systems. Instead of relying on the "creative few" for technical leadership, these "superprograms" begin to require the "creative many." As a consequence, such efforts may require engineering talent that is qualitatively different from the present output from today's graduates.

INFRASTRUCTURE CHANGES

Ideally, when the foregoing tasks are completed, the Phase II study should be in a position to describe:

- What the engineering elements are and how they interact;
- The current status of each element, and its current strengths and weaknesses;
- How (and how quickly) the major elements tend to respond to change; and
- What the range of future stimuli and pressures on the engineering infrastructure might be.

In fact, some of these understandings may only be qualitative, at best. Nonetheless, the study group should be able to proceed to a convincing discussion of the kinds of infrastructure changes that appear desirable or necessary for the foreseeable future, where in the system they should occur, and when they should occur.

The range of possible changes in the education and utilization of engineers that might be identified can be very large. At least the following topics need to be examined:

- The status of engineering vs. other societal needs
  - Priorities for the most talented manpower
  - Priorities for other resources

- Preengineering education
  - The needed content, quality, and intensity of preparation in mathematics, science, humanities, and social science
  - The impact of career guidance counseling

- Undergraduate education
  - Nature of the curricula (e.g., fundamentals vs. specialization, uniformity vs. diversiication, segmentation of engineering)
  - Curricula content, new fields (e.g., flexibility in response to state-of-the-art and to industrial needs)
  - Orientation (preparation for industry vs. preparation for consulting practice)
  - Facilities (e.g., adequacy of capacity, level of sophistication)
  - Teaching productivity (use of modern techniques and procedures)
  - Computer technology (integration into the educational process)
  - Alternative delivery methods (e.g., co-op and other programs)

- Graduate education
  - Foreign students
  - Student quality (competitive opportunities)
  - Research funding (uncertain behavior)
  - Equipment facilities (e.g., institutional sharing, consortia)
  - Role of industry
  - Role of government

- Faculty concerns
  - Availability (intense competition for limited talent pool)
  - Recruitment/retention (attractiveness of other career options)
  - Competence (e.g., responsibility of faculty to remain current in their field of expertise)
  - Motivation (e.g., the quality of work situation in terms of compensation, prerequisites, workload, personal satisfaction)

- Continuing education/professional self-renewal
  - Motivation for personal/professional self-renewal
  - Cost sharing
  - Outreach (on-site delivery)
  - The role of professional societies, industry, academia
  - The quality of available education

- Financing professional education
  - Relative importance to society
  - Role of government
  - Role of industry (individual companies; consortia)
  - Role of educational institutions
  - The student's share

- Quality of work life
  - Challenging work
  - Involvement with management
  - Communication within the organization
  - Opportunity and growth
  - "Dual Ladder" advancement
  - Compensation
  - Affirmative action
  - Recognition and other intangible awards
  - Flexible hours
  - Stability and security

- Utilization on a national scale
  - Engineers as a national resource
  - Size of the engineering reservoir
  - Deployment against problems and needs
  - Image and recognition
  - Retention
  - Impact of the computer on the profession
  - National R&D policy
  - Continuing education
  - Productivity and cost of engineering
  - Engineers in management and government.

A thorough examination of these kinds of topics will enable the Phase II study group to make findings and recommendations of a critical nature . Areas warranting such conclusions would be expected to include:

The needs of universities, so that they can remain at the leading edge of the various engineering disciplines and developments in an inflationary environment. The issues have both financial and pyschological content, and include the maintenance and renewal of facilities and equipment; the maintenance and evolution of academic and research programs; loss of endowment strength; and the health and well-being of faculty, including material considerations, teaching loads, pressure, and pace.

The needs of industry and government for a cadre of engineers in a wide variety of disciplines for use in expansions, new opportunities, and for replacement and evolution. These technically trained personnel must fill roles in a very complex environment, and the necessary match between the skills of future engineers and the needs of industry and government deserves careful study.

The needs of society to maintain U.S. technical preeminence and/or predominance in an era of intense and growing foreign competition. The nation requires engineers who can solve pressing problems with a high technical content, as well as those who can contribute to continued increases in the standard of living by utilizing lower levels of technology. It needs engineers who can establish and monitor technical quality standards to ensure the protection and safety of society.

RECOMMENDATIONS

The United States has been well served by the engineering community and can continue to be well served if reasonable solutions to the current and potential problems that beset the various elements of the community can be identified and implemented. Some of the problems, particularly in the educational sector, are of such clear and present concern that they should receive immediate ad hoc attention by appropriate groups. However, a coordinated, comprehensive study of engineering over the rest of this century, as described in the body of this report, is also needed, and *we recommend that such a study now be conducted.* Only upon completion of such an effort will it be possible to convincingly establish whether there is an impending overall engineering crisis, as some suggest, that will require far-reaching system corrections, or whether the engineerring community can, with less drastic modifications, be expected to maintain the resiliency that will warrant our continued national confidence. Thus, *we recommend that the study be carried out within the next two years.*

Study Objectives

The engineering community is large, widely dispersed, and very diversified. Any study of the problems of the community as a whole will either have to focus on some level of generalizations or will have to be very long and costly. Because the availability of the findings may be critical to the future viability of the system, *we recommend that the study pursue an overall analysis of the engineering infrastructure, rather than attempting to catalogue the individual problems and concerns of every engineering discipline or engineering field.* However, because many of the actions that may be called for will have to be taken at detailed levels to be effective, *we recommend that the study structure be developed so that later, supplementary studies of specific fields and disciplines can be undertaken by an extension of the study protocols.*

It is further recommended that the study

- *Define the elements of the engineering infrastructure and their interrelations;*
- *Determine the current status of the principal infrastructure elements and their historical development over the past 50-60 years, including their historical relations to major economic, political and technological events;*

- *Identify the stimuli for decision-making for the main infrastructure elements and their typical response modes;*
- *Provide projections of future events that might affect the engineering system over the rest of the century; and*
- *Recommend policies and programs to make necessary changes or additions to the engineering infrastructure, and indicate the priorities for such actions.*

The study must recognize the state of flux that exists with regard to the availability of resources for the support of engineering institutions and programs. *A priori* assumptions about the government role may not be tenable. Thus, *we recommend that the study identify options for private industry and the academic institutions, as well as for the government, in the actions needed to enhance the engineering system.*

Study Organization

While it is contemplated that the recommended study will address a broad spectrum of interrelated issues, it will be comprised of a combination of separate study tasks. To ensure that the necessary interrelations among these tasks are present and consistent, *it is recommended that the study be conducted under the aegis of an overall steering committee.* This committee should provide broad policy guidance, assign specific tasks, review the progress and outputs of the task groups, and act as the principal authors of a final report containing the study's findings and recommendations.

After appropriate task assignments are defined by the steering committee, subcommittees, each consisting of a chairman and additional members from the steering committee, together with additional experts appropriate to the topic, might undertake some of the specific studies. In conduct of such task assignments, it may be useful for the subcommittees to establish working groups for specific subtopics.

Some of the subtopics may lend themselves to separate investigations that could best be carried out as individual efforts or may require more concentrated attention than may be possible from part-time volunteers. *We recommend that consideration be given to commissioned studies and papers, as warranted.*

In particular, those parts of the study that relate to quantitative data on the engineering workforce, either current or historical may benefit from coordinated analysis and interpretation by outside bodies of experts. *We recommend that working arrangements be established with active manpower analysis groups for the collection,classification, and evaluation of data related to the engineering workforce.*

Study Participants

If the recommended study is to have a positive impact, it will have to be received and viewed by the various elements of the engineering community as a balanced, reasoned exposition of engineering and its problems. Equally important, however, the report will have to be viewed by non-engineering decision makers as sound and objective, particularly insofar as recommendations for action may conflict with other national priorities. Support for the study's conclusions will be enhanced if a widely representative group of interests are involved in the study. *It is recommended that a broad group of industrial, governmental, and academic leaders concerned with engineering, including spokesmen for the principal engineering societies, be invited to participate in the study together with representatives of other professions and societal segments.*

APPENDIX A

RECENT STUDIES OF ENGINEERING EDUCATION PROBLEMS

Within the past year, several groups have looked at the problems facing the engineering education establishment in the United States Some of the studies have resulted in formal reports, others have been of a less formal character or are still in progress.

In April, 1980 the National Academy of Engineering issued a report[1] of a study based on approximately 400 responses to a survey of the engineering community regarding important issues in engineering education, institutional support of engineering schools, university/industry/government relationships, and the social context of engineering. By design, the study focused on the framework for decision-making, rather than on the decisions themselves, and did not purport to offer specific solutions for specific problems. In October, 1980 the NAE extended its consideration of the university/industry/government relationships in a symposium reported in 1981.[2] There was no effort to reach any consensus position on the problems of academe or their solutions.

At the request of President Carter, the National Science Foundation and the U.S. Department of Education jointly prepared a report on technical education problems that was released in October, 1980[3]. The report addressed educational concerns at the secondary as well as collegiate and post-collegiate level for science, mathematics, and engineering. With regard to engineering, the report identified a faculty shortage in most fields, as well as a short-term engineer shortage in many fields. In the longer term, the report was optimistic about engineering supply/demand relationships, except possibly at the PhD level. The study recommendations were general, and largely involved proposals for increased federal support programs.

On December 3-4, 1980 a conference at Shakertown (KY) considered the dimensions of the engineering faculty shortage, and concluded that it was of crises proportions. In the report of the conference[4], the American Association of Engineering Societies and/or the National Academy of Engineering were urged to prepare a definitive "white paper" on the shortage.

An Engineering Foundation Conference, sponsored by the Accreditation Board for Engineering and Technology was held July 26-31, 1981 in Rindge, N.H. on the Aims and Goals for the Eighties in engineering education. The proceedings report[5] identified two "prime critical" issues. First, the ratio of students to faculty members in engineering schools in the United States has increased to a level that is decreasing the quality of engineering education. Second, insufficient numbers of U.S. citizens are entering graduate engineering schools, and this will result in a decreasing percentage of U.S. citizens who will become engineering professors, from which a long-term decrease in the nation's creativity and productivity in high-technology areas will follow. There was no unanimity of views on the most effective and practical solutions to these issues.

In addition to these published studies of engineering education problems, the American Electronics Association published an extensive forecast of the technical manpower requirements in the electronics industries through 1985[6]. The survey, taken in the spring of 1981, considered the paraprofessional as well as professional needs of the industry.

Several other studies are either still underway, or will not appear in published form. The Engineering Deans Institute devoted their meeting of April 12-15, 1981 to symposium discussions of university relationships with industry and the federal government. In the summer of 1981, IEEE/Spectrum convened a roundtable discussion of possible programs to overcome faculty shortages, equipment renewal problems, student support programs, and the like. An account of the discussions will appear in the November, 1981 Spectrum A second meeting is planned to try to sharpen suggestions for actions.

The National Association of State Universities and Land-Grant Colleges has recently established a steering committee to develop a program of industry cooperation with land grant schools for the solution of engineering education problems. A major conference for the discussion of possible actions is being planned for the spring of 1982.

A two-year study has just been launched by the American Society for Engineering Education to generate possible solutions to the engineering faculty shortage. This study is being funded by grants from eight industrial corporations made through the American Association of Engineering Societies.

Each of these study activities has contributed to an improved understanding of the concerns of academe and/or the industries to which their graduates flow. So far, however, the studies have tended to look only at pieces of the overall engineering equation, or have represented the views of only relatively small numbers of the participants in the engineering process.

REFERENCES

1. Task Force on Engineering Education of the National Academy of Engineering. "Issues in Engineering Education - A Framework for Analysis." Washington, D.C.: National Academy of Engineering, April 1980.

2. The National Academy of Engineering. "Academe/Industry/Government: Interaction in Engineering Education." A Symposium at the Sixteenth Annual Meeting-October 30, 1980, Washington, D.C. Washington, D.C.: National Academy Press, 1981.

3. The National Science Foundation and the U.S. Department of Education. "Science & Engineering - Education for the 1980's & Beyond." Washington, D.C.: U.S. Government Printing Office, 1980.

4. Pleasant Hill Education Conference, December 30, 1980. "National Crises-Severe Engineering Faculty Shortage." Shakertown at Pleasant Hill, Harrodsburg, Ky, 1981.

5. Engineering Foundation Conference, July 26-31, 1981, Rindge, N.H. "Engineering Education - Aims & Goals for the Eighties." New York, N.Y.: ABET Headquarters, 1981.

6. American Electronics Association. "Technical Employment Projections of Professionals and Paraprofessionals 1981-1983-1985." Palo Alto, Calif.: American Electronics Association, 1981.

APPENDIX B

POTENTIAL OUTLINE OF PHASE II REPORT

I Introduction

- A. Engineering as a field
- B. The engineering system
- C. Engineering goals
- D. Goals of engineering education
- E. Perceptions which call for this study

II Historical Perspective

- A. The development of the present system
- B. Good, bad, and neutral experiences
- C. The dynamics
- D. Value added

III The Present Status of the Engineering System

- A. Inventory
  1. Manpower
  2. Sourcing and development institutions
  3. Post-entry support structures
- B. Response dynamics of
  1. Students
  2. Universities
  3. Faculties
  4. Engineers
  5. Industries
  6. Government
  7. Professional societies and academies
  8. Scientists
- C. Stimulants to institutional changes
- D. Stimulants to individual choices

IV Short-term Issues

- A. Manpower shortages and surpluses
- B. Dislocations

C. Fields on hold
D. Reindustrialization and productivity

V Long-term Scenarios and their Possible Impacts

VI Costs of Insufficient and Surplus Engineering Resources

A. Economic
B. Human
C. Industrial

VII Future Engineering Capacities and Capabilities

A. Measurement problems
B. Possible improvements
C. Responsibilities

VIII Findings

IX Recommendations

APPENDIX C

POSSIBLE FUTURE ENGINEERING/PROBLEM INTERFACES

At its initial meeting, the Committee considered a list of almost 150 topics that might be contemplated as important potential driving forces on the engineering community over the next twenty years as a consequence of their potential economic, political, or technological impacts on the American scene. For purposes of discussion, these were grouped into twenty-eight subcategories within the major categories of

- o The Economy
- o National Defense
- o Quality of Life
- o Energy
- o Transportation Systems
- o Information Systems.

After a general consideration of the types of issues and problems that might be posed by each topic, each attendee was asked to rate four characteristics of each subcategory:

- o The importance of the topic of our national future;
- o The technological content of the topic;
- o The opportunity for the application of technology to an improved understanding of the topic; and
- o The adequacy with which the topic is presently being addressed.

Based on the ratings, the topics that were identified by the group as having the common characteristics of a high potential importance to the national future, a high technological content, and the opportunity for the application of technology to the improved handling of the topic included:

- o Productivity improvements
- o Foreign competition
- o Quality improvements in goods and services
- o Growth/energy relationships

- Technical parity in defense
- Reliability and maintainability of defense systems
- Environmental quality
- Urban problems
- Health care
- Education systems
- Energy
- Intercity transportation systems
- Information systems

Most of these topics were considered to be receiving only relatively low or moderately effective current treatment and could, presumably, be better handled if decisions were to be made to employ technologies appropriate to their nature.

Based on this brief exercise, it was the opinion of the committee that this or similar approach could be readily applied to the identification of a range of problem-scenarios that might impact on the engineering community in a significant way, and from which selections could be made for detailed impact analyses.