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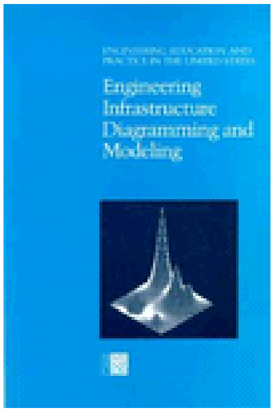

Engineering Infrastructure Diagramming and Modeling

Panel on Engineering Infrastructure Diagramming and Modeling, Committee on the Education and Utilization of the Engineer, National Research Council

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Engineering Education and Practice in the United States

Engineering Infrastructure Diagramming and Modeling

Panel on Engineering Infrastructure Diagramming and Modeling
Committee on the Education and Utilization of the Engineer
Commission on Engineering and Technical Systems
National Research Council

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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 report 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 purposes 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.

Support for this work has been provided by the National Science Foundation, the Department of the Air Force, the Department of the Army, the Department of Energy, the Department of the Navy, and the National Aeronautics and Space Administration. Additionally, assistance has been provided through grants from the Eastman Kodak Company, Exxon Corporation, the General Electric Company, the IBM Corporation, the Lockheed Corporation, the Monsanto Company, and the Sloan Foundation.

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Preface and Acknowledgments

This report by the Panel on Infrastructure Diagramming and Modeling forms an integral part of the overall study by the Committee on the Education and Utilization of the Engineer, performed under the auspices of the National Research Council. The most significant product of this panel's effort appears as Chapter 3 ("Defining the Engineering Community") in the full committee report.*

The material included in this panel report, however, goes far beyond that found in Chapter 3 of the main committee report. In fact, the definition of the engineering enterprise in the United States, the identification of its full infrastructure, and its subsequent description and analysis by diagramming and modeling were fundamental to much of the work of other panels and to that of the full committee. The definitions adopted by the panel are controversial to some, in that they permit inclusion of practitioners who do not hold the academic or professional registration credentials deemed by many as essential to inclusion in the engineering fraternity. In adopting the definitions presented, the panel made no value judgments as to the validity of credentials or the inclusion of "improperly" credentialed persons in the engineering community. Rather, the panel was concerned with identifying all those engaged in or directly supporting the engineering enter

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* *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future* (Washington, D.C.: National Academy Press, 1985).

prise in the United States so that a complete and proper description and analysis of that enterprise was possible.

The Panel on Infrastructure Diagramming and Modeling originally convened under the able leadership of Erich Bloch, now director of the National Science Foundation (NSF). Most of the difficult research and analysis was performed under his guidance, as was the preparation of the initial draft report. When Mr. Bloch left the panel to assume his NSF duties, I was asked to guide completion of the report. I was able to do that only with the assistance of Arnold R. Eshoo of IBM and William H. Michael, Jr., overall staff director for the study. To both I owe a debt of gratitude. Also, on behalf of both Erich Bloch and myself, I want to thank and commend all the panel members and the staff for their outstanding efforts. It was a pleasure to work with such a fine group of professionals.

We also extend our appreciation to many other individuals and their organizations for contributions to the panel's overall effort: to Bernard J. Cullen, consultant, McBer & Company; Alan Fechter, National Science Foundation and National Research Council; Daniel E. Hecker, Bureau of Labor Statistics (BLS); and Charles Falk, Michael Crowley, and Louis G. Mayfield of NSF.

And finally we acknowledge the following individuals who made presentations to the panel (topic in parentheses following name):

Alan Fechter, National Research Council (*Ph.D. Supply*)

Robert C. DauffenBach, Oklahoma State University, and Jack Fiorito, University of Iowa (*Mathematical Manpower Models*)

Patrick J. Sheridan, Engineering Manpower Commission (*EMC Data Bases*)

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Eugene Seeloff, Lehigh University (*Lehigh University Placement Activities*)

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P. H. Hubbard, American Electronics Association (*AEA Technical Employment Projections, 1983–1987*)

DONALD G. WEINERT

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INTRODUCTION

The Committee on the Education and Utilization of the Engineer (CEUE) established the Panel on Infrastructure Diagramming and Modeling to carry out the following activities:

- study the structure and dynamics of the engineering community;
- assess in quantitative terms the engineering community—its past, present, and future;
- assess the underlying driving forces and causes that influence both entrance into and exit from that community;
- identify the sources from which the community draws its members and those predictors and relationships that would be useful in assessing the state of the engineering profession; and
- arrive at findings, conclusions, and recommendations with regard to these matters.

In order to achieve its mission expeditiously the panel undertook five major tasks, which are described briefly below.

1. **Defining Engineering** Early in the panel's work, it became apparent that many organizations, societies, and government agencies have their own definitions of engineering. Also, different engineering studies and data bases use different definitions in arriving at conclusions. It also became clear that new developments in engineering had

rendered some of the older definitions obsolete. It was therefore important for the work of this panel and of the whole committee that a common definition be provided. The definition eventually formulated (see Chapter 1) comprises engineering, the engineering community, and the engineer, as well as engineering support groups.

2. **Determining Influences on the Engineering Community** The panel studied both past and possible future influences on the engineering community to establish their likely effects on the structure of engineering and on its population (see Chapter 2).
3. **Diagramming** The panel considered a schematic flow diagram to be essential in understanding the complexity and dynamics of the engineering community. Basing its efforts on the definitions it had developed, the panel gave a great deal of attention to formulating a comprehensive diagram. The diagram it produced includes the major sources, flows, and activities of the engineering community and represents a realistic assessment of the complexity and interaction of this community. The diagram has various levels of detail (see Chapter 3).
4. **Modeling** As a further aid in understanding the dynamics of the engineering community, a simplified model was developed to study current and near-term causal relationships. Models sponsored by the National Science Foundation (NSF) were used to gain further insight into current and near-term relationships and to study long-term relationships and effects. The panel's modeling work consisted of two parts: (1) an evaluation and critique of existing approaches to modeling; and (2) development of a simple, first-order model (the "CEUE model") of the engineering community to permit exploration of "what-if" types of questions with regard to supply and demand (see Chapter 4).

   Readers should note that the CEUE model is used in a simplistic predictive fashion, and caution must be exercised not to attribute accuracy beyond the model's intended capabilities.
5. **Analyzing Data Bases** The panel undertook a thorough analysis of existing and relevant data bases in an effort to determine the size of the engineering community and to provide a source of data for trend analysis. (Such quantitative data analysis was needed to identify trends and changes that are important in assessing the supply, demand, and utilization of members of the community.) The data base sources were then used to quantify the major parameters, stocks, and flows of the diagram referred to above. The panel's work focused on compatibility and consistency among data bases, as well as on their completeness (see Chapter 5).

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The findings, conclusions, and recommendations of the panel are presented below. Where possible, they are organized to parallel the major tasks of the panel; however, many derive from the insights gained from multiple and diverse viewpoints considered by the panel.

Engineering and the Engineering Community

There is considerable diversity of opinion among individuals, groups, and organizations on what constitutes engineering and what criteria should be used for a quantitative assessment of the engineering pool. Once the panel had chosen and applied criteria, however, the engineering community was found to be larger than merely the sum of persons with engineering degrees. In fact, the engineering community contains significant numbers of

- individuals with baccalaureate or higher degrees in science and mathematics who have acquired status as engineers;
- people whose highest degree is an associate engineering degree or a technologist degree and who have acquired status through experience as engineers or as engineering technicians or technologists; and
- individuals who over years of experience and/or noncollegiate training have acquired the skills and knowledge to do bona fide engineering work.

Furthermore, the practice of engineering is split among many disciplines, not all of which share a common technology base. Also, many engineering tasks now are multidisciplinary; computer science, systems analysis, business administration, economics, psychology, and other knowledge areas may play major roles in both the engineering problem statement and its solution. In addition to this new multidisciplinary environment is the fact that the engineering community is in a continuous state of flux—the tasks of engineering, its boundaries, and its tools are changing.

As a result of these findings, the panel concluded that any definition, model, survey, or data base must recognize and encompass the diversity of engineering. And so must programs aimed at the education or enhancement of the engineering profession.

Thus, the panel recommends that *the National Academy of Engineering and the National Science Foundation, in cooperation with the Engineering Manpower Commission and the professional engineering societies, develop continuing programs to heighten public, government, and industrial awareness of the importance of engineering to*

U.S. technological competitiveness and the need for an adequate supply of highly qualified engineers. Furthermore, these organizations should develop the necessary data and analytical tools to permit continuing analysis of the engineering profession in order to provide information on which educational institutions, engineering societies, government agencies, and industries may base decisions and actions.

Definitions: Engineers, Engineering, and the Engineering Community

There is wide variability across the engineering community regarding the meaning of the terms *engineer* and *engineering*. From the standpoint of the educational system, the primary criterion is the degree granted; in the workplace, however, job content and performance are most important.

The lack of commonly accepted definitions of engineer and engineering complicates the collection, reporting, and analysis of data pertaining to the quantity and quality of engineers and others involved in engineering-related work. Existing data strongly reflect this definitional ambiguity. In addition, current definitions do not adequately describe the larger *community of engineering,* which includes those involved directly in the engineering enterprise, those acting in a support capacity, and those potentially qualified for engineering-related work but not now so engaged.

The panel concluded that a comprehensive, commonly accepted definition is necessary as a basis for describing the engineering community in broad terms. Such a definition is also essential to permit the accurate collection, display, and analysis of data about the profession. Finally, it is a prerequisite for reaching appropriate decisions that will affect the engineering community.

The panel also concluded that any definition of engineers, engineering, and the engineering community must simultaneously encompass the mission/ philosophy, credentialing, function, and context of operation in which engineering is performed. It must anticipate and allow for the development and addition of new technology and new branches of engineering, as well as the decline of existing ones.

As a result of these findings, the panel recommends that *the definitions presented in Chapter 1 of this report be accepted by the engineering community and used as the basis for data collection, reporting, and analysis by all organizations involved in such activity*.

Forces Affecting the Engineering Community

Graduates of four-and five-year engineering programs constitute the single major source of personnel to fill new engineering job openings. However, the increasing utilization of two-year pre-engineering programs in community colleges has had a significant influence on the size of the engineering community and on the demand for four- and five-year engineering education. Among the external forces affecting flows into the engineering community, the size and quality of the high school graduating pool have had a significant influence.

The panel also found that there is considerable supply elasticity for the engineering community. For example, there are large numbers of engineers without engineering degrees, who presumably entered the engineering labor force when demand was high. There also appears to be a large "strategic reserve" represented by those who have qualified as members of the engineering community in the past but who either left the profession entirely or, more likely, are currently engaged in managerial and engineering support activities.

Other forces with significant influence on the practice of engineering and on flows into, within, and out of the engineering community are social factors (public attitudes); economic factors (compensation for engineers, availability of capital for investment); political factors (e.g., public policy, regulation); and technological factors (rate of obsolescence of engineers, discovery of new technologies, and the need for increased productivity). A factor of special interest that is having a growing influence on the engineering community is the emerging interest of women and minorities in engineering as a career. In addition, the supply of people for the engineering faculty pool is limited by the stringent credentials for admittance. This situation is compounded by the observed decline in the relative number of U.S. Ph.D.s and the proportion of those who enter teaching at the undergraduate and graduate levels.

Imbalances between supply and demand created by sudden or unanticipated changes are redressed by a combination of events: increased production from the engineering education system, sometimes at the expense of changing admission and graduation standards; flows from the reserve and support pools; and flows from the hard and soft sciences and other sources.

Historically, adjustments by the engineering community to the forces affecting it appear to have been roughly adequate in most instances to meet technological challenges and the needs of society.

However, because of increasingly rapid changes in technology and related industrial and societal pressures, as well as increasing competition from abroad, the panel concludes that industry, government, and the engineering profession must pay continuous and close attention to the internal and external forces affecting the size and capability of the engineering community in the United States.

Based on the considerations delineated above, the panel recommends that

- *engineering societies at state and local levels urge state education departments and local school boards to establish and implement adequate math and science curriculum standards to prepare qualified students for entry into college engineering programs without the need for remedial work;*
- *the engineering societies and schools develop active guidance programs for elementary and secondary school systems to encourage qualified students to enter engineering;*
- *community colleges be encouraged to expand their pre-engineering programs in close cooperation with the four-year engineering schools;*
- *all employment sectors be encouraged to study and continuously monitor the utilization of engineers to ensure that they realize their full capabilities; and*
- *special programs be developed to interest qualified women and minorities in engineering.*

Diagramming and Modeling

The panel found it difficult if not impossible to understand the flows and relationships within the engineering community without a comprehensive schematic portrayal of that community. Since no such comprehensive schematic portrayal existed, however, the panel developed a comprehensive flow diagram of its own, which proved adequate to display this complexity.

The development of the schematic portrayal of the engineering community revealed a complexity in structure and flows greater than is generally understood. Construction of the flow diagram also led to the identification of two large populations not previously considered part of the community—a technical reserve and a pool of staff support.

In relation to modeling, the panel found that existing models pertaining to engineering do not encompass the entire engineering community as defined in Chapter 1 of this report. Nor do they track the flows as represented by the diagram described in Chapter 3. A model structured to match the flow diagram should allow broad sensitivity analyses of flows and resulting impacts on the pools identified. This is more important than striving for absolute accuracy.

It must be said that the rapidly changing and unpredictable character of technology and of the economic, political, and social influences affecting the profession militate against development of a reliable predictive model. This, however, does not preclude the use of a model for gaining insights and drawing broad conclusions about cause-and-effect relationships and for focusing on shortcomings of data. Thus, diagramming and modeling of the engineering community are necessary activities for understanding the complexity and interaction of the various stocks, flows, and interrelations within the engineering community.

The panel recommends that *the flow diagram presented later in this report be adopted by the engineering community and used as a basis and guideline for collecting data, analyzing flows and relationships, and projecting the effects of changes in flows and relationships*.

Data Bases

Data on the engineering community are collected, analyzed, and reported by several different organizations, each for its own particular purpose. (The most extensive data bases have been developed by the National Science Foundation, National Research Council, American Association of Engineering Societies, Engineering Manpower Commission, Bureau of Labor Statistics, and National Center for Education Statistics.) The diverse structure and purposes of the existing data bases make it extremely difficult to integrate or compare data. For example, for 1982 there are estimates of the numbers of engineers in the United States that vary from 1.2 million to 1.9 million. Without standard measurement criteria there is no discernible way to reconcile these differences. As a result, these inconsistencies make it difficult to develop either quantitative or qualitative descriptions of the engineering community.

Further limitations of the data bases include the following:

- There are major gaps in the data particularly for the numbers and flows of those members of the engineering community without engineering degrees (e.g., technicians, technologists, and individuals with degrees in other fields).
- Existing data on employment of engineers by specific industry are inadequate. Since industry is the major employer of members of the engineering community, this constitutes a serious gap in the data bases.

- Sample size and structure of existing data will permit limited individual disaggregation for sex, minorities, employment specialty, degree, employment sector, and age, but multiple disaggregations (e.g., sex and age) are restricted.
- None of the existing data bases, either singly or in combination, can adequately support the flow diagram and model referred to in Chapters 3 and 4 of this report. Current data do not permit complete quantitative or qualitative analysis of flows into, within, and out of the engineering community.
- There are reasonably good data on students at the secondary, undergraduate, and graduate levels and on flows of degreed engineers. These data, however, permit only limited disaggregations of persons within the working pool.
- Almost no data exist on the technical reserve.

As a result of these findings, the panel concluded that available data bases provided only a limited understanding of the engineering community as defined in this report. Therefore, it is virtually impossible to construct an accurate and internally consistent picture of the entire engineering community, including those engaged in engineering as well as those engaged in engineering support, over the last 20 years. To assess the technological strength and competitiveness of the United States accurately, there must be complete and accurate data on engineering and scientific manpower.

The panel thus recommends that *the National Academy of Engineering periodically convene a conference of all organizations involved in the collection, analysis, and reporting of engineering manpower data with the goal of making those data more complete, more accurate, and more compatible.*

In addition, future data collection efforts should be guided by an agreed-upon overall schematic of the engineering community, similar but not necessarily identical to the flow diagram described in this report.

Existing data collection efforts should be modified to provide, as a minimum, information on all segments of the engineering community as depicted in the flow diagram in this report. (Chapter 5 provides more specific recommendations.)

Efforts also should be undertaken to ensure the accuracy and reliability of existing data bases and current methods of data collection and analysis. In particular, the reliability and accuracy of the Occupational Employment Survey should be evaluated because of its impact on decisions affecting the engineering community.

1

Definition of Engineering

INTRODUCTION

The advancement and application of technology have become increasingly complex activities and involve people with a broad scope of training, skills, and experience. Engineering has not in the past and will not in the future be the sole province of individuals with degrees from accredited engineering institutions and engaged in designing products or services.

To analyze the complexity of the subject, the Panel on Infrastructure Diagramming and Modeling went about the task of defining engineering by first discussing, as individual topics, the mission of engineering, the credentials of engineers, the functions and activities within engineering, and the context of engineering work. Based on these discussions, the panel arrived at the following conclusions:

- The mission of engineering is to apply knowledge derived from mathematical and physical sciences in creating or delivering useful products or services of a technical nature.
- The credentials of people in the engineering field include experience in applications as well as evidence of formal education and training.
- The functions of engineering extend from research through technical operations and include direct management of technical or engi

neering activity but do not include general management or such support functions as purchasing or sales.

- The context of engineering includes business, government, academia, and self-employment.

In parallel with the preparation of working definitions, the panel also developed a flowchart of education and engineering experience, ranging from secondary school graduation through an individual's exit from engineering work. To quantify the flows, the panel reviewed available data sources. In doing so, it became clear that there is an *engineering community* composed of people who are or have been actively engaged in work within the mission and context of engineering but who may have had no formal training in engineering. They may have degrees in the physical or biological sciences, in liberal arts, or, particularly, in computer science, or they may have had no formal training at all before entering engineering work. It also became clear that the engineering community included individuals who had had training or experience in engineering but who were not currently employed in either engineering or in engineering support. These people may be employed in general management in technology-based companies or elsewhere in the economy, or they may be unemployed, but they are a reserve pool that is available, particularly to industry, for engineering work if there is a surge in demand for engineering talent.

Together, the structural and flowcharting approaches led to the working definitions that are given below. For simplicity, the panel combined the mission and context aspects into the single definition of *engineering,* and it defined the *engineering community* broadly enough to include people with current or recent credentials or employment in engineering work. The definitions of *engineer, engineering technologist,* and *engineering technician* differ only slightly from those used in other studies. (For a discussion of the historical context of definitions of *engineer* and *engineering,* see Appendix A.)

The notion, however, of an "engineering community"—far broader than a "community of engineers"—is a departure from previous studies and is a novel feature of the panel's work. Chapter 3 shows clearly and quantitatively why it is important to recognize the contributions, at both professional and support levels, of people without formal engineering training, and of the "engineering reserve," which contains people available to meet surges in industrial demand.

DEFINITIONS

As discussed in the Executive Summary and in Appendix A, the panel found it necessary to establish definitions, with particular application to its own work and to that of the Committee on the Education and Utilization of the Engineer, and on which to base accurate data collection and display, and analyses of data about the profession. The panel recognizes that this challenging task is subject to controversy and, indeed, emotionalism, but it was essential for the purposes described. The following definitions were adopted by the panel.

Engineering Business, government, academic, or individual efforts in which knowledge of mathematical, physical and/or natural sciences is employed in research, development, design, manufacturing, systems engineering, or technical operations with the objective of creating and/or delivering systems, products, processes, and/or services of a technical nature and content intended for use.

Engineering Community People meeting at least one of the following conditions:

- actively engaged in engineering, as defined above;
- actively engaged in engineering education;
- qualified as an engineer, engineering technologist, or engineering technician, as defined below, and actively engaged in such engineering support functions as engineering management or administration, technical sales, or technical product purchasing;
- qualified as an engineer, engineering technologist, or engineering technician, as defined below, who was but is not now actively engaged in engineering, engineering education, or engineering support.

Engineer A person having at least one of the following qualifications:

- college/university B.S. or advanced degree in an accredited engineering program;
- membership in a recognized engineering society at a professional level;
- registered or licensed as an engineer by a governmental agency;
- current or recent employment in a job classification requiring engineering work at a professional level.

Engineering Technologist A person having at least one of the following qualifications:

- a bachelor's degree from an accredited program in engineering technology;
- current or recent employment in engineering work, but lacking the qualifications of an engineer as defined above.

Engineering Technician A person having at least one of the following qualifications:

- a degree or certificate from a one-to three-year accredited technical program;
- current or recent employment in engineering work, but lacking the qualifications of an engineer as defined above and at a lower job level than that of an engineering technologist.

2

Forces Affecting the Engineering Community

The second major task undertaken by the Panel on Infrastructure Diagramming and Modeling was to determine some of the forces, both external and internal, that affect the engineering community and, in turn, the practice of engineering. A number of these forces are discussed briefly below, followed by a summary of the panel's views on the outlook for engineering practice in the future.

EXTERNAL INFLUENCES

Some of the major external factors influencing the engineering community include (1) the supply of and demand for engineering students and graduates (see Appendix B), (2) government policies, (3) industrial and business practices, (4) societal expectations and realities, and (5) technological changes.

Supply of and Demand for Engineering Students and Graduates

The number and academic quality of the students who begin and complete degrees in U.S. engineering institutions have a major impact on the engineering community. A few decades ago, fewer than half of the engineers in the United States had an engineering or college degree, and a significant proportion had no college degree. Since World War II, the supply of new entrants to the field has been dominated by those graduating from U.S. engineering institutions with a B.S. degree or higher. As a result, the current engineering work force and the larger engineering community include primarily B.S. degree recipients. Also, the number of individuals going on to receive master's and doctoral degrees is increasing, and the number graduating with B.S. degrees is increasing at an even faster rate.

The supply of engineering students and eventual graduates is directly related to birth rates, demographic factors, and the relative attractiveness of engineering when compared to other intellectually demanding and quantitatively oriented career fields. Additional supply factors include the available educational resources and the standards of quality for admission to and retention in engineering courses of study. The extent to which the engineering community assimilates individuals who do not have engineering degrees and retains those with engineering degrees or equivalent experience continues to affect the demand for engineering graduates.

In recent years, there has been a significant increase in the number and proportion of women, minorities, and foreign nationals who enter and graduate from U.S. engineering institutions. These increases are expected to continue, but future rates for women and minorities are directly and indirectly related to the extent to which the engineering community assimilates these new entrants. The foreign national engineering supply, on the other hand, is dependent on U.S. policies with regard to immigration and emigration.

Government Policies

Government policies and priorities have a major impact on engineering practice and hence on the engineering community. Tax policies affect investment and the engineering work generated by such investment. Antitrust laws affect cooperative research and development among industries. Environmental laws spur technologies in waste treatment and disposal. Defense and space programs give impetus to a wide range of existing technologies and spawn a host of new ones. In addition, government levels of support for graduate education in engineering and science and university-based research and development have an impact, especially on engineering facilities. In the aggregate, government policies strongly affect supply, demand, and quality in the engineering community.

Industrial and Private Business Practices

Currently, about three-fourths of the total number of U.S. engineers are working in private industry; about one-half of those work in manu facturing. Because of these high proportions, the economic growth and personnel policies of private industry continue to be dominant factors influencing the engineering community. Private industry considers the members of the engineering community as a vital human resource. And although the engineering community looks to industry as the primary user of its services, a strong engineering community, supported by a versatile educational system, is essential to maintaining the availability of the engineering resources needed by industry. In the meantime, industry is obligated to use those resources effectively. Key factors in that utilization seem to be challenging work, adequate compensation, and enlightened management.

Societal Conditions

There is every reason to believe that rapid and accelerating societal changes will continue to have an impact on the engineering community. Major events both within and beyond society's control have significant technological impacts and directly affect the engineering community. For example, cold and hot wars and peace and disarmament all have major implications for the work activities of the engineering community. And issues such as environmental protection, world energy supplies, national defense, industrial productivity, space exploration, transportation, communications, health, and agricultural productivity continue to be major societal concerns that can generate demands on the resources of the engineering community. Some of these issues are affected by government policies and business practices, but many of them depend more on the larger society's needs, goals, and priorities.

Responses to Change

The emergence of new sources of engineering graduates (e.g., women and minorities}, the ability of the engineering community to assimilate a wide range of practitioners (technicians, technologists, nongraduates), changing utilization patterns, and new technologies have all combined to create a remarkably versatile and responsive engineering community.

INTERNAL FACTORS

In addition to the external factors that affect the engineering community, there are several internal conditions that constitute important influences. These influences are primarily related to three factors: the activities of the professional engineering societies, legal policies related to engineering licensing and certification, and communications and relations within the engineering community. Some progress has been made in achieving cooperation between the various engineering and engineering-related societies, including the organization of the American Association of Engineering Societies. Because of the diversity of the engineering profession, however, there continues to be considerable difficulty in organizing and maintaining a unified engineering organization similar to the American Medical Association in medicine and the American Bar Association in law. There seems to be a genuine desire among engineers to have a unified voice, especially at the national level on matters of public policy. However, the autonomy of the individual engineering societies and the diversity of engineering continue to inhibit the development of a single umbrella organization.

A related issue involves the relationship of engineering societies to other scientific and technological organizations, such as the American Physical Society, the American Chemical Society, and the American Society of Certified Engineering Technicians. Engineers and engineering organizations often feel that they are excluded or have a limited voice with regard to public policy and support of programs for science, engineering, and technology. On the other hand, there is some disposition on the part of engineers and engineering organizations to exclude technologists and their organizations from participating in the formulation of engineering-related decisions and policies. Evidence of engineering's concern about its relative status with regard to science can be found in proposed legislation to change the National Science Foundation to the National Science and Engineering Foundation. Its ambivalence about the role of engineering technologists can be seen in the efforts by some engineering societies to exclude technologists from engineering organizations and to minimize their voice in regard to science, engineering, and technology.

Perhaps the most important internal factors affecting the engineering community are its own actions, primarily through the engineering societies, to define the community, to influence standards for credentialing, to set standards for education and ethical standards for practice, and to guide young people into engineering careers. These activities can and do have profound effects on the size, composition, and competence of the engineering community. They also affect its self-image and the image it projects to the public at large.

TECHNOLOGY AS A DRIVING FORCE FOR CHANGE

In addition to societal influences that affect the engineering community, the results of engineering tasks—that is, the field's own products and the changes these products bring about—have an equal or sometimes greater influence on the composition of engineering, the engineering disciplines, the tools of engineering, and its methods and approaches. And although it is true that the emergence of new engineering disciplines as well as the transformation of existing ones has occurred throughout the history of engineering, today's changes are more pervasive and the rate of change is greater than in the past.

Perhaps the cause of the greatest series of changes is the confluence of semiconductors, computers, and telecommunications in information technology. This confluence, in turn, has contributed to the movement of U.S. industry and the U.S. economy from one predominantly concerned with the generation of materials and products to one of providing information and services. This major shift of focus is the fundamental cause of change in the engineering disciplines.

To address this movement, changes in curriculum content as well as in existing engineering disciplines are occurring. The most profound is the change in the field of electrical engineering. Today, in many schools, it not only comprises the electric power and electronics disciplines, but it also increasingly includes, as a minimum, computer engineering and, in some instances (i.e., at the Massachusetts Institute of Technology and Stanford University), computer science. These changes are also carried into the industrial environment. (The biggest subgroup within the Institute of Electrical and Electronics Engineers (IEEE) is the computer society, certainly an expression of the increasing computer content in this profession's activities.) It would be a serious omission, therefore, if we did not consider tasks related to computer systems as engineering activities, their products as engineering designs, and their practitioners as part of the engineering community.

New technologies also create allied disciplines that evolve separately from and independently of the classical engineering disciplines and their foundations. Some examples of these allied disciplines are information systems technologies, artificial intelligence, industrial technologies of many kinds, and other science-related disciplines. Also, fundamental disciplines merge. The best example of such a phenomenon is bioengineering, a field in which, over time, an increasing number of engineers will be employed.

The conclusion to be drawn from the changes cited above is that the definitions of engineering and of the engineering community must be modified to make them consonant with changes to existing engineering disciplines and to the emergence of new ones. This the panel has sought to do, as noted earlier in this report (see Chapter 1).

EXPECTED IMPACT OF ADVANCES IN ENGINEERING AND TECHNOLOGY

The panel noted important and critical advances in engineering and technology that are likely to have significant impact on the engineering community. It offers the following views on the nature of the expected impacts:

- The computer and the information explosion will have a profound impact not only on the future methods of engineering but also on the future problems, designs, and systems for which engineers will be responsible.
- The engineering community will become more sensitive to the rapid developments that are taking place in computer science, information systems, industrial technologies, and other related disciplines. Those disciplines are developing curricula and training programs as well as career development programs independent of the engineering community. Individuals trained in these areas will provide a broad range of talent capable of undertaking work currently and previously done by engineers. These disciplines are likely to become major sources of influence and power in some of the new emerging technologies, and it will become increasingly important to have closer cooperation between these new emerging disciplines and the larger engineering community.
- The aging of the engineering work force and the declining number of 18-year-olds, combined with an increasing demand in some disciplines, point to the possibility of spot shortages in the supply of engineers in the late 1980s and 1990s. The resulting increased demand for engineers should produce a significant but necessarily time-delayed response to these shortages. These assumptions are supported by the following: A large cohort of engineers is approaching retirement, and demographic trends suggest that college enrollments will begin to fall in the late 1980s or sooner. Retirements will increase replacement demands whereas enrollment decline may operate to decrease the new supply. Also, responses to the resulting imbalances can be expected to experience time delays, which are inherent in adjustments in the educational systems that provide new engineers. However, the very wide

spectrum of talent and the diversity of the supporting engineering infrastructure should be sufficient to avoid a major supply/demand crisis (except for one that might be associated with a major war or catastrophes).

- Present trends indicate that the makeup of the engineering work force and its supporting infrastructure is likely to become more diverse with increasing numbers and proportions of women, minorities, and foreign nationals. These compositional changes will be relatively slow, however, in view of the more than 1 million U.S. males that dominate the current makeup of the engineering work force. The dependency on foreign nationals as graduate students and as engineering faculty is likely to continue as U.S. engineering and engineering education become more international in scope. The panel anticipates that these new constituencies will have an important and constructive impact on engineering and on the larger engineering community.
- Graduate work in engineering will probably become more commonplace, with the master's degree in engineering assuming increasing importance for work in research, development, and creative design. The doctorate in engineering will continue to be the primary requirement for engineering college teaching, university research, and engineering educational administration.

Although the M.B.A. will continue to be an important graduate degree for a small proportion of B.S. engineering graduates, there is a parallel need for graduate education or continuing education programs that focus specifically on engineering management. In addition, the doctorate in engineering and/or science probably will become increasingly important in industry and government, not only in research and development and its management but in some high-technology areas as well.

- Engineering education, engineering practice, and engineering jobs will become increasingly international in scope and will present not only unprecedented opportunities but major challenges as well.
- Increasingly, undergraduate engineering education will become a new form of general education for a technological age. Engineering education and the engineering community will face growing inside pressures for improvements in basic and engineering science education as well as in design and practice. There will also be increasing outside pressures to develop greater sensitivity to national, world, and societal problems related to science, engineering, and technology.
- In response to these developments, the engineering community will face increasing demands for both breadth and depth in education,

training, and experience. To meet these demands, engineering will need to provide not only higher levels of education and training beyond the traditional B.S. degree, but expanded and more readily accessible continuing education for its various engineering constituencies. Those constituencies will represent an increasingly broader spectrum of talent. These will range from two-year associate degree engineering technician and four-year bachelor's of engineering technology programs through bachelor's, master's, and doctoral degree engineering programs to advanced and professional degree programs in science and management. Mobility between and within engineering-related disciplines will continue to increase.

3

Flow Diagrams of the Engineering Community

INTRODUCTION

Several supply-and-demand flow diagrams and models of scientific and engineering manpower have been developed by investigators seeking to understand the dynamics of the nation's technical resources and to make projections of future needs. Some overlap greatly (see the examples cited in notes[1][2][3][4][5][6] at the end of this chapter). The very broad definition of the engineering community adopted by the Committee on the Education and Utilization of the Engineer (CEUE) required a much more detailed and comprehensive flow diagram than those associated with existing models. However, much was borrowed from the good work already done, and the resultant diagrams are compatible in concept but not necessarily in detail.

It was recognized at the beginning of the study that some kind of analytic framework would be required for understanding and quantifying the dynamics of the engineering community. Beginning with the secondary education process, there are obviously many options available to individuals, many of which lead to entry into the engineering community. In addition, there is a known high degree of mobility among the various sectors of the community and a steady attrition of people leaving the community, either temporarily or permanently. Indeed, the work of the Panel on Infrastructure Diagramming and Mod eling disclosed that the process is much more complex than was expected, and this observation has been identified as a major finding of the committee.

The panel addressed the need for an analytic framework by developing a diagram depicting the various populations in the engineering community and how people move between and within them. The diagramming process fulfills several important purposes in understanding the engineering community:

- It provides a graphic representation of the complex flows and interactions of the people who make up the engineering community.
- It reduces ambiguity and confusion in dealing with technical human resources by establishing a consistent set of definitions and relationships among the groups involved.
- It facilitates the identification of options for entry into and departure from the various segments of the manpower system.
- It provides a framework for empirical assessment of the importance of the various populations and the magnitude of movements of people within the engineering community and between that community and the rest of society.
- It provides a basis for tracking past changes in characteristics of the engineering community and projecting future problems.
- It provides a foundation for studying the behavior of key subsets of the general population.

DESCRIPTION OF THE DIAGRAMS

The flow diagrams prepared by the panel are constructed as a series of boxes (representing pools, or groups of people with common characteristics) and directional lines (representing the movements of people among the different populations). For clarity in the discussion that follows, pools or populations will be referred to as *stocks,* and the movement of people as *flows*.

The diagrams represent a one-year slice of time. Stocks are determined at some arbitrary point in time; then, based on the flows measured during the subsequent year, new stocks are determined for a year later.*

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* In reality, stocks and flows are not determined for exactly the same time periods because of variations in data collection. For example, stocks and flows in the employment areas are usually on a calendar-year basis, whereas the educational areas are based on the school year. Unless there is some major perturbation in one of the data elements, these inconsistencies are not expected to affect conclusions significantly.

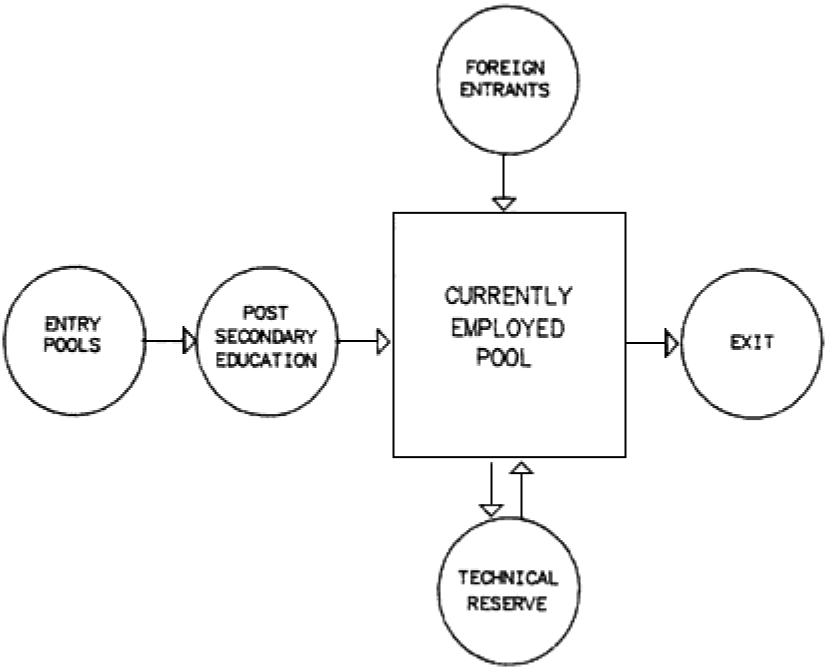


Figure 1
Basic flow diagram of the U.S. engineering community.

Four types of flow diagrams are required to describe completely the transactions in the engineering community. Each is described below in some detail.

Basic Flow Diagram

The basic flow diagram developed by the panel is shown in Figure 1. In its simplest form the flow of people moves as follows: (1) from the entry pool of students admitted to higher education institutions, to (2) students engaged in educational preparation for entry into (3) employment in the engineering community, followed by (4) exit from the engineering community, either on a temporary or permanent basis.

Comprehensive Flow Diagram

The comprehensive flow diagram shown in Figure 2 is an expansion of the basic flow diagram and includes all the significant stocks and flows of the engineering community. The names given to these stocks

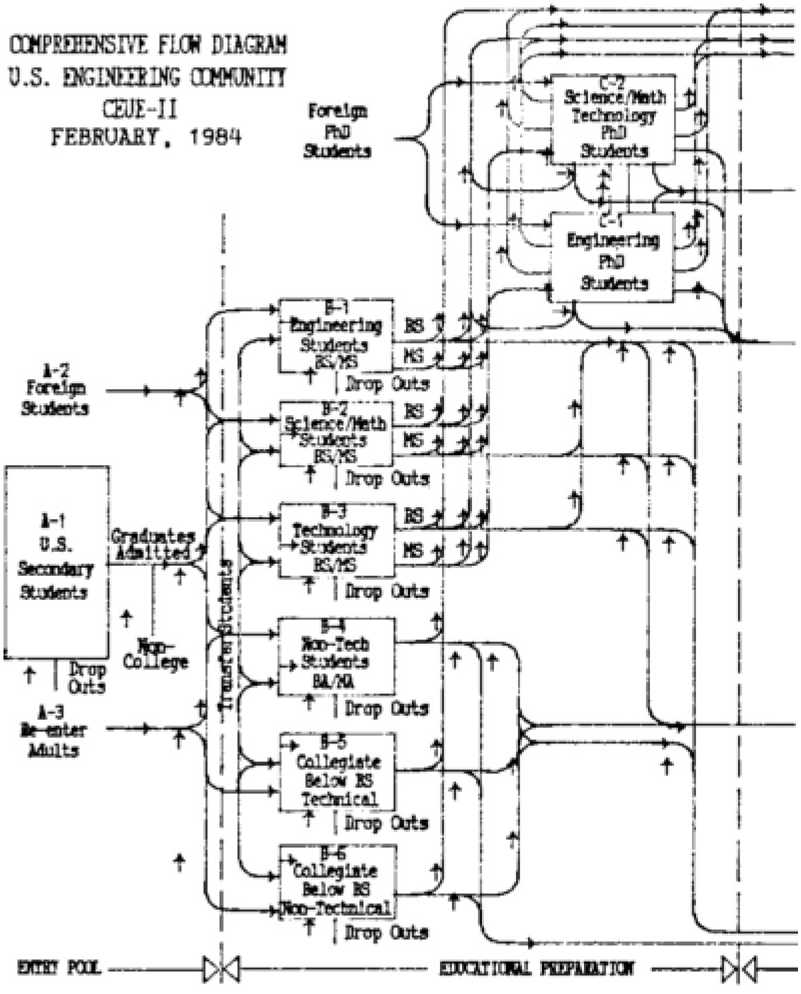
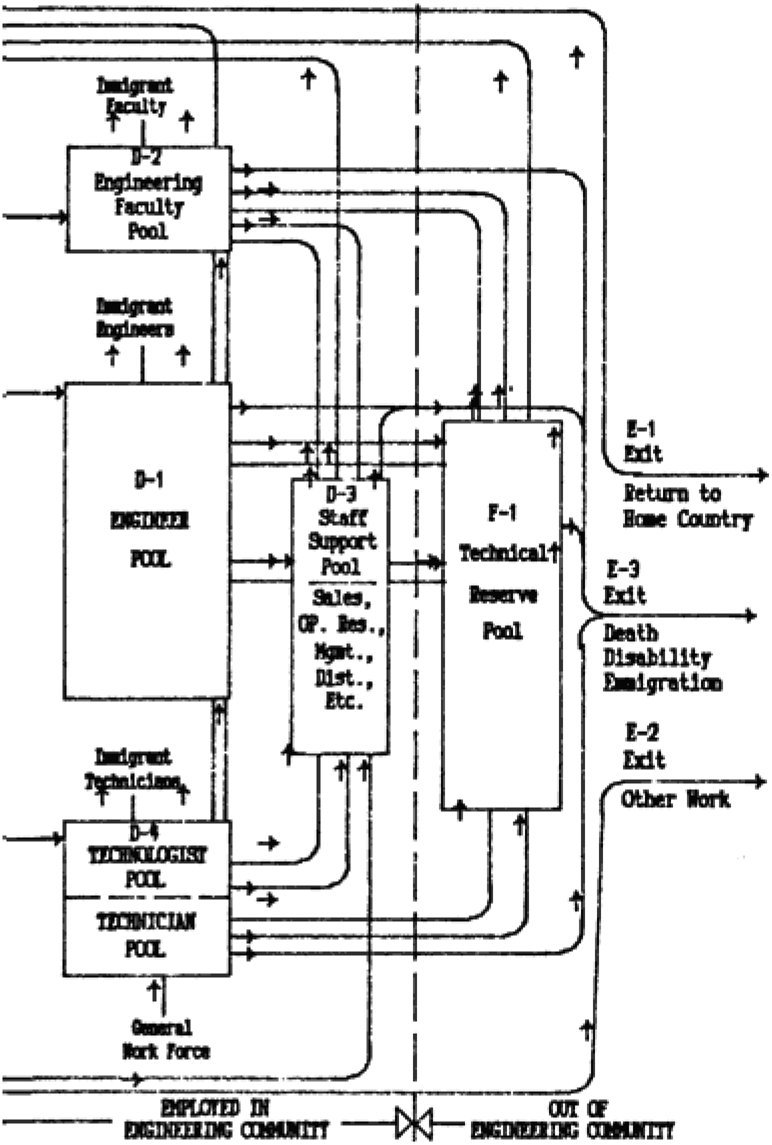


FIGURE 2 Comprehensive flow diagram of the U.S. engineering community.

Figure 2
Comprehensive flow diagram of the U.S. engineering community.


Immigrant Faculty
D-2 Engineering Faculty Pool
Immigrant Engineers
D-1 ENGINEER POOL
D-3 Staff Support Pool
Sales, OP. Res., Mgmt., Dist., Etc.
F-1 Technical Reserve Pool
Immigrant Technicians
D-4 TECHNOLOGIST POOL
TECHNICIAN POOL
General Work Force
E-1 Exit
Return to Home Country
E-3 Exit
Death Disability Emigration
E-2 Exit
Other Work
EMPLOYED IN ENGINEERING COMMUNITY
OUT OF ENGINEERING COMMUNITY

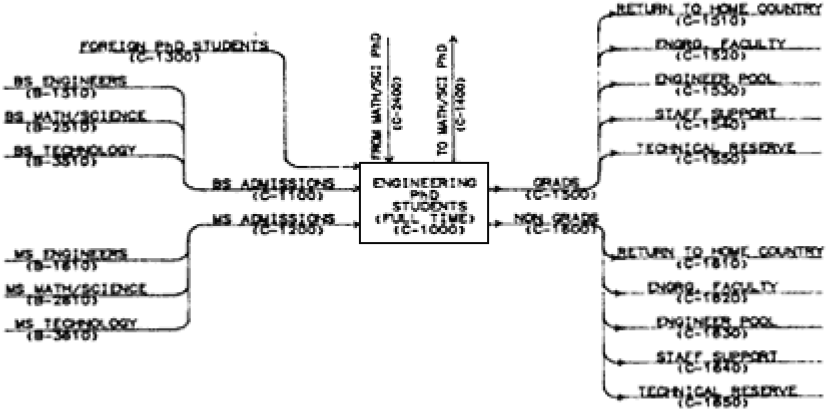
and flows are consistent with the basic definitions contained in this report (see Chapter 1) for *engineering community, engineer, engineering technician,* and *engineering technologist*. The definitions of all other terms used in the flowcharts are contained in the Glossary in Appendix C. Special mention is needed for two stocks that were defined during the diagramming process to describe adequately all the major options of people moving among the engineer, faculty, and technician pools:

- **Staff Support**—that group of people giving active support to engineering activities but not currently functioning under the definitions of engineer, technician, or technologist. Included in staff support are such activities as technical management, procurement, sales, operations research, and personnel. Most of these individuals have been classified as engineers, technicians, or technologists in the past, and many will reenter those pools during their careers.
- **Technical Reserve**—that group of people who are qualified (with reasonable training) to function in one of the technical stocks (i.e., as a member of the faculty, engineer, technician, or technologist pools or as staff support) but who are currently outside the engineering community. Included are retirees, people who are employed in other fields, individuals who are not working, those in military service, and so forth. These people are a potential source of supply under certain conditions, such as during a national emergency.

Detailed Flow Diagrams

The detailed flow diagram focuses on one particular stock and shows all the separate flows into and out of that stock. It is only at this level of detail that it is practical to identify numbers of people associated with the stocks and flows. A consistent numbering system, which is described in the "Labeling" section of Appendix C, has been devised to label the data elements for each stock and flow. An integral part of each detailed flow diagram is a table showing the labels, a description of the stocks and flows, and the data elements.

Nineteen detailed flow diagrams have been developed to describe the engineering community completely; they are included in Appendix C. One example, "Flows Affecting Engineering Ph.D. Students," is shown in Figure 3 in this chapter. The number of students in engineering Ph.D. programs at the start of the reference period is represented by the rectangular box and the label C-1000. Eight significant sources are shown for new entrants into the graduate program, and 11 possible



Flows Affecting Engineering Ph.D. Students (Full Time), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
C-1000	Engineering Ph.D. Students	5.8	14.8	14.5
C-1100	B.S. Admissions to Engineering Ph.D., From:	—	—	—
B-1510	B.S. Engineers	—	—	—
B-2510	B.S. Math/Science	—	—	—
B-3510	B.S. Technology	—	—	—
C-1200	M.S. Admissions to Engineering Ph.D., From:	—	—	—
B-1610	M.S. Engineers	—	—	—
B-2610	M.S. Math/Science	—	—	—
B-3610	M.S. Technology	—	—	—
C-1300	Foreign Ph.D. Students	—	—	—
C-2400	Transfer From Math/Science Ph.D.	—	—	—
C-1400	Transfer to Math/Science Ph.D.	—	—	—
C-1500	Ph.D. Engineering Graduates	0.8	3.4	2.5
C-1510	Return to Home Country	0.05	0.2	0.24
C-1520	To Engineering Faculty	—	0.79	0.45
C-1530	To Engineer Pool	—	2.06	1.46
C-1540a	To Staff Support—Management	—	0.21	0.24
C-1540b	To Staff Support—Technical Support	—	0.14	0.12
C-1550	To Technical Reserve	—	—	—
C-1600	Leave Ph.D. Program	—	—	—
C-1610	Return to Home Country	—	—	—
C-1620	To Engineering Faculty	—	—	—
C-1630	To Engineer Pool	—	—	—
C-1640a	To Staff Support—Management	—	—	—
C-1640b	To Staff Support—Technical Support	—	—	—
C-1650	To Technical Reserve	—	—	—

Figure 3 Example of a detailed flow diagram and its accompanying table (from Appendix C of this report).

destinations are shown for people leaving graduate programs, some with and some without the Ph.D. degree. Frequently, there are data elements for which a satisfactory value is not known to exist; this prevents rationalizing the flow system. Four options can be considered for reducing these data problems:

1. If analysis indicates the element to be small in relation to the other flows, it can be eliminated from the diagram or placed at zero.
2. A range of values or a most likely value may be estimated by persons most familiar with the system.
3. If data are available for the other elements in the system, a value can be calculated by difference.
4. Additional data can be collected if the data element is deemed important enough to the total system.

Disaggregated Flow Diagram

The disaggregated flow diagram facilitates the study of subsets of the stocks and flows that make up the comprehensive diagram. In principle there are many ways in which the data can be disaggregated. Some are of great interest to certain sectors of the engineering community, and some may have a substantial bearing on the "quality" of the community. Examples of specific inquiries about the system are the following:

- Do electrical, chemical, and other types of engineers display similar flow patterns?
- How important are foreign nationals in each element of stocks and flows?
- Do different sectors of the economy (e.g., the electronics industry, the federal government) have different sources of supply?
- What is the makeup of the group that flows into the staff support stock and what does this do to the composition (quality) of the engineer pool?

Unfortunately, available data are not necessarily adequate for studies of the type suggested by the questions listed above. However, data disaggregation (see Figure 4) can be used to suggest answers to these types of questions.

THE BALANCE EQUATION

In addition to serving as a graphic representation of the engineering community, the flow diagrams also represent a slice of time in the dynamics of the system. The numbers of people in the various stocks at some point in time are affected during a one-year period by the flows into and out of the system, resulting in a new set of values for the stocks at the end of the period. We have borrowed the following simple equation from traditional energy and material balances:

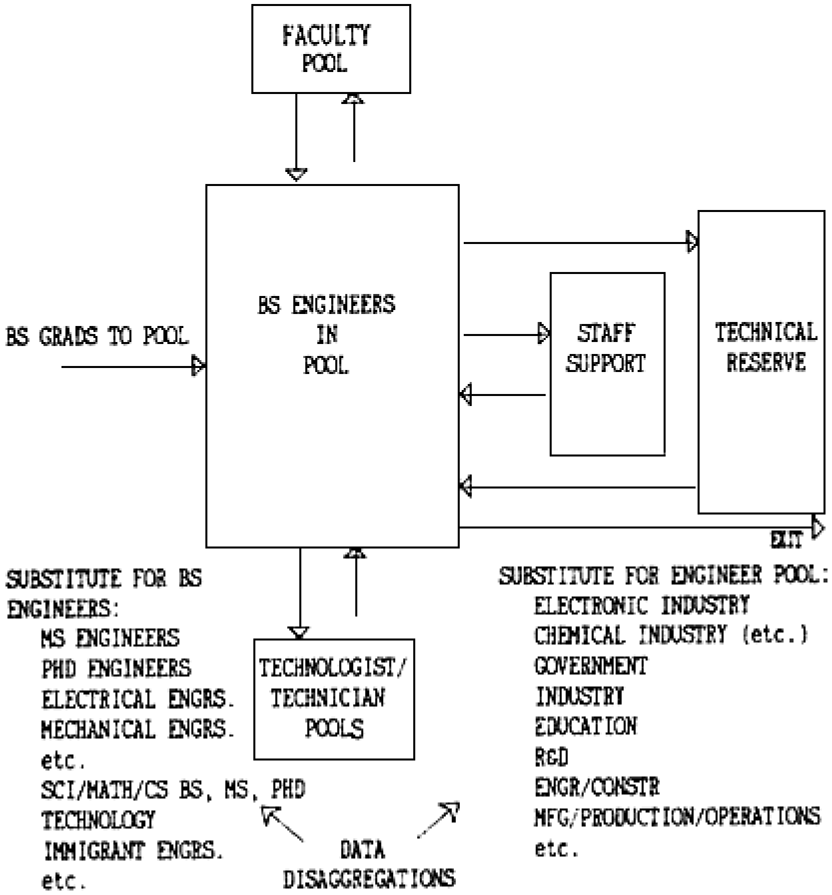


Figure 4
Flows of B.S. scientists and engineers within the engineer pool system.

$$Q_1 + \Sigma f_i - \Sigma f_o = Q_2$$

where
Q_1 = number of people in stock at beginning of period,
Σf_i = sum of flows into the stock,
Σf_o = sum of flows out of the stock,
Q_2 = number of people in stock at end of period.

The same simple relationship applies to the stocks that make up the engineering community and to the system as a whole. Applied to the detailed flow diagram for engineering Ph.D. students used as an example in Figure 3, the basic equation becomes:

C1000 (1983) + [C1300 + C1510 + C2510 + C3510 + B1610 + B2610 + B3610 + C2400] - [C1400 + C1510 + C1520 + C1530 + C1540 + C1550 + C1610 + C1620 + C1630 + C1640 + C1650] = C1000 (1984).

A logical extension of the balance equation is the important matter of supply and demand for the various categories of participants in the engineering community. Using the engineer pool as a sample case, demand resulting from new job openings can best be expressed as the following:

Demand = Attrition + Net Job Growth,

where

Attrition = people leaving the engineer pool for any reason during the measurement period.

Net Job Growth = new jobs created in the pool minus any current jobs eliminated.

Supply for the engineer pool can be expressed as:

Supply = New Graduates + Transfers in + Immigrants,

where

New Graduates = recent graduates from any discipline or at any degree level who enter the engineering pool during the measurement period.

Transfers in = persons who enter the pool from a different stock such as faculty, technician pool, staff support, or technical reserve.

Immigrants = persons entering the engineer pool for the first time and whose educational preparation was *not* in the U.S. higher-education system.

Demand can differ from supply by either a *positive* number, in which case there are net vacancies in the pool, or by a *negative* number, in which case there is net unemployment in the pool. The equation for this relationship is:

Demand = Supply + Net Vacancies - Net Unemployment.

Combining the above equations produces the following:

Net Job Growth + Attrition = New Graduates + Transfers in + Immigrants +
Net Vacancies - Net Unemployment.

DATA AVAILABILITY

A detailed discussion of the data bases needed to quantify the flow diagrams is included in Chapter 5. As mentioned earlier, it was apparent from the panel's earliest deliberations that there are serious gaps in the data required to describe the general system. Furthermore, the data available from different sources are inconsistent because of differences in definitions, collection methods, and time frames. Given these problems, the quality of data in the different areas of the engineering community has been characterized for this study as (a) relatively good, (b) relatively incomplete, or (c) very limited. The areas are listed below, followed (where applicable) by the best source of data currently available.

There are relatively good data on the following:

- College enrollments (Engineering Manpower Commission (EMC) of the American Association of Engineering Societies (AAES))
- College graduates (EMC)
- Ph.D. activities (National Academy of Sciences (NAS))
- Engineering faculty (American Society of Engineering Education (ASEE))
- Engineer pool (National Science Foundation (NSF))
- Foreign students (EMC)

The data are relatively incomplete in these areas:

- Staff support (NSF)
- Technical reserve (NSF)
- Technician pool (Bureau of Labor Statistics (BLS))
- Flows out of engineering/technician pools to retirement, due to death and disability, and to nonengineering work (BLS)

The data are very limited in the following areas:

- Immigration
- Emigration
- Reentering adults
- Community college graduates
- Mobility within pools
- Disaggregation by sector (government/industry/education), discipline (mechanical/electrical engineering), industry (auto/energy/electronics), job function (research/manufacturing/design), geography, and race and sex.

MAJOR DRIVING FORCES

The engineering community as defined in this report is basically a robust system. It has experienced rapid growth in the past 10 years (see Figure 5). Large increases in demand, high economic growth, defense buildups, and demographic shifts have all been accommodated by the community in the past. (Market forces and other drivers of supply and demand are discussed in some detail in other reports of this overall study, particularly in the CEUE summary report[7] and in two other panel reports.[8]) The accommodations noted probably could be supported again by the elastic supply of people who may be marginally qualified but are anxious to enter the engineering community in a proper allocation of job assignments.

Another factor that has not as yet been accounted for quantitatively is the continuous productivity improvements resulting from new approaches and tools that engineering has at its disposal (e.g., modeling and simulation replacing experimentation). If it is assumed that every job vacancy will eventually be filled by some person, the problem becomes one of quality and utilization instead of raw numbers. (Of course, a real or perceived shortage of qualified engineers in any field could have a strong effect on growth and new ventures in that area.)

With these considerations in mind, the driving forces that most affect the orderly flow of people through the engineering community can be identified.

Demand-Side Forces

Net New Demand for Engineers The normal ebb and flow of business cycles, R&D activity, and growth or contraction in individual industries result in a net change in engineering jobs over a given mea suring period, assuming perfect mobility of engineers from one kind of work to another and from one part of the country to another. But would engineers displaced from the energy or steel industries in the Midwest move to the West Coast and be retrained for the electronics industry? Probably not, and to the extent that this kind of immobility is operative, people from the engineer pool would enter the technical reserve stock, and the opening thus created would be filled by a new entrant into the engineering community or by an individual who was being

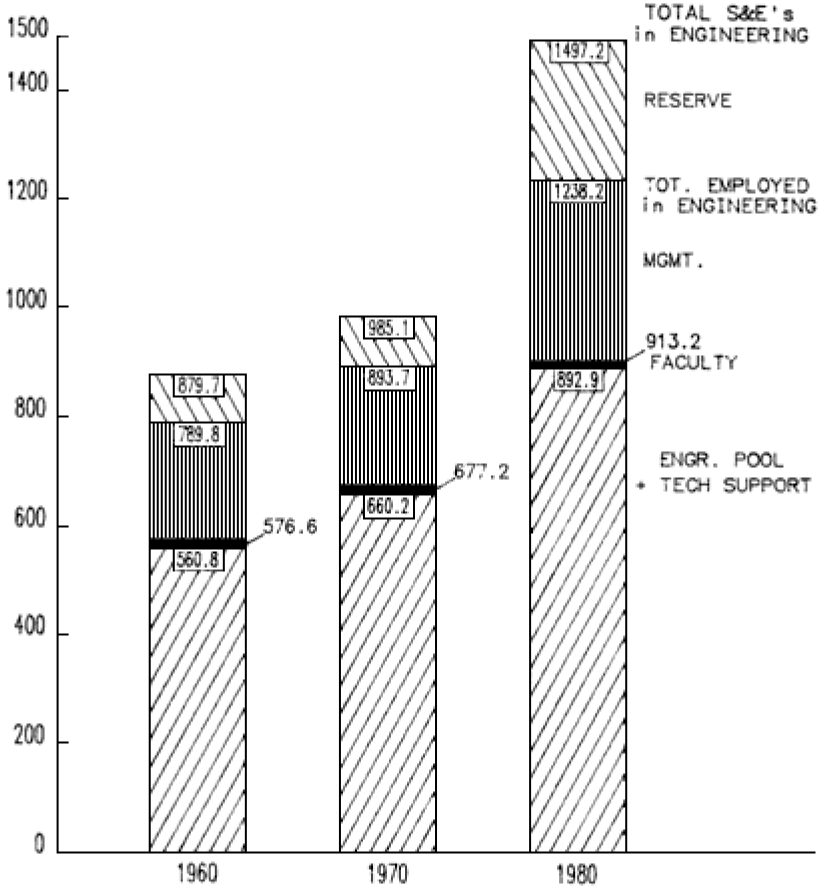


Figure 5
Scientists and engineers in the engineering work force (in thousands) for 1960, 1970, and 1980. Source: Data from National Science Foundation, *U.S. Scientists and Engineers: 1982*. NSF 84-321 (Washington, D.C.: NSF, 1984).

upgraded from the technologist/technician pool. Net new demand will vary considerably from year to year, but it is projected as an annual average of 45,000 persons per year from 1983 through 1995.[9]

Net New Demand for Technologists/Technicians The same factors described above for engineers apply, with an important additional variable, to technologists and technicians. The amount of technical assistance required for engineering activities varies widely from field to field. The introduction of computers, robotics, and other high-technology devices can be expected to increase the demand for technicians and technologists in virtually all industrial operations. The alternative to employing technicians and technologists for such technical assistance is to use engineers for this kind of work. However, this would result in severe underutilization and loss of productivity and could result in a reduction in the supply of engineers because of a perceived deterioration in their work environment.

Transfers Into the Staff Support Area A characteristic of engineers (or law graduates) is that a high proportion move into some management or staff function early in their careers. It is estimated that on the average about 60,000 people will leave the engineering pool annually between 1985 and 1995.[9] If we make the assumptions that the graduate engineers in the pool perform better than the entrants from secondary sources and that "promotion" into management is based on previous performance, then engineering graduates will move into staff positions in higher proportions than will others in the pool. This creates additional cause for concern about the quality of the engineers left in the pool. The high rate of transfer into staff support and management positions is an important driving force that is deeply embedded in U.S. industry practice. A basic change in the financial and psychic reward systems would be required to retain more engineers in the engineer pool. This is highly unlikely and may not be desirable. Continuing education for those remaining in the pool can help offset any loss of high-quality performance capabilities.

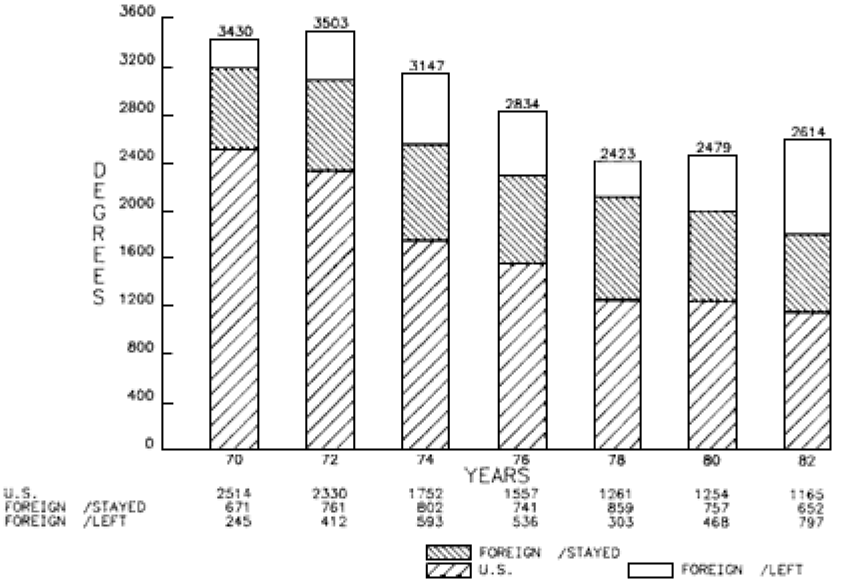
Demographics of the Engineer Population The high concentration of the general population in the age group above 50 years applies equally to engineers.[10] The age distribution is skewed further by the high number of engineers entering the profession in the industrial boom following World War II. The result is that a disproportionate number of engineers in the engineer pool, as well as in the engineering faculty and staff support pools, will be leaving the engineering community through retirement and death in the near future. More needs to be learned about this impending influence, which will surely intensify the faculty shortage problem and put pressure on the demand for new engineers both by depleting the engineer pool and by creating more "opportunities" in the staff support pool for those in the engineer pool.

Supply-Side Forces

The Number of Engineering Graduates There is little question that the preferred source for new entrants into the engineer pool is the recent graduate in engineering from a college or university. It is a characteristic of the system that the number of new job openings in engineering is equal to the supply of new graduate engineers, except in selected disciplines where there are shortages. Thus, the inflow from other sources, such as foreign-trained engineers, other scientists, and upgrades, is determined by the difference between demand and the size of the graduating class in engineering. The numbers of new engineers are affected by the demographics of college-age young people, by the proportion opting for engineering, and by the capacity of the engineering schools as limited by facilities and faculty. The effect of a shortage of new graduates on the system can be very serious with respect to a single discipline. (For example, we may be entering a period when a shortage of electrical and computer engineers could substantially curtail the growth of so-called high-tech industries.)

The Number of New Engineering Faculty The availability of a qualified body of faculty is an important driving force in the dynamics of the engineering community. Faculty shortages can affect the supply of new graduates. The current much-publicized "shortage" of engineering faculty is the result of convergent factors, several of which are portrayed in Figure 6 and noted below:

- The number of engineering Ph.D. degrees granted has not kept pace with growth in undergraduate degrees and the engineering work force in general.[11]
- An increasing number of Ph.D. degrees are granted to foreign nationals who do not enter the U.S. work force.[12]
- The nature of industrial research is increasing the demand for engineering Ph.D.s in private sector research and development.[13]
- The age demographics of the present engineering faculty suggest an increase in the attrition rate over the next decade.[11]



	70	72	74	76	78	80	82
U.S.	2514	2330	1752	1557	1261	1254	1165
FOREIGN /STAYED	671	761	802	741	859	757	652
FOREIGN /LEFT	245	412	593	536	303	468	797

Figure 6
Ph.D. engineering degrees awarded to U.S. citizens and foreign nationals, 1970–1982. Source: National Research Council, *Summary Report 1982: Doctorate Recipients From United States Universities* (Washington, D.C.: National Academy Press, 1983).

For the reasons stated above, the entry of new faculty into the pool is a crucial element. It would be expected that the first effect of a faculty shortage would be lowered educational quality as a result of teaching overloads and large classes. To counter such problems, a majority of engineering departments are currently practicing some method for limiting enrollment. As would be expected, the restrictions are most severe in the areas where demand for undergraduate engineers is the greatest—currently, in electrical and computer engineering. Redirecting the faculty from disciplines of lesser demand to those in high demand is an approach that is not being given enough focus.

The Foreign Student Population With 8 percent of bachelor's degrees, 26 percent of master's degrees, and 39 percent of Ph.D. degrees in engineering currently being granted to noncitizens with temporary visas,[14] the impact of foreign students is obviously an important driving force. The arguments for and against admission of foreign students into U.S. institutions are complex and cut across political, social, and economic issues. An analysis of the merits of government and university policy in this area is beyond the scope of this study. From the standpoint of impact on the engineering community,

- the presence of foreign undergraduate students in U.S. engineering departments substantially increases the teaching load of the existing faculty resources;
- since domestic U.S. demand is generally being met by the available supply, noncitizen B.S. graduates who do not remain in the United States represent either some measure of excess capacity or some measure of excessive strain on existing capacity in the engineering education system;[15]
- the foreign graduate students at the M.S. and Ph.D. levels who do not elect to stay permanently in this country, while undoubtedly making important research contributions during their graduate work, reduce the flow of high-level talent into the U.S. engineering community, both as faculty and in practice.

To illustrate the impact of foreign students, it is only necessary to consider the consequences of policies that would (a) severely limit the admission of foreign students to the engineering curricula—a significant increase in the number of U.S. engineering admissions and graduates would follow, but graduate schools would be hard pressed to function; (b) greatly relax immigration requirements for noncitizen engineers—the supply to the engineering community at all graduate levels would be substantially increased, presumably also increasing research and teaching capability. At the same time, it could be argued that opportunities for U.S. citizens in the highly desirable field of engineering would be reduced, and that a serious "brain drain" could result in developing countries.

LIMITATIONS OF THE FLOW DIAGRAMS

The diagrams developed in this study are limited to flows of people who are full-time students or employees and to stocks that represent highly aggregated groups of people. To fully understand the complicated dynamics of the engineering system, further work needs to be done in several other areas that are noted briefly below.

Part-Time Students

In addition to the full-time students tracked in the diagrams, a large and presumably growing number of people are enrolled in courses for credit while still being employed. Included in this category are employees attending a community college for entry into the technician pool, technicians and technologists trying to upgrade their status while working, and engineers pursuing a master's or even a doctoral degree. Since the panel's diagrams are designed to be in numerical balance, it is not feasible to count the same person both as an employee and as a student. However, such additional education clearly implies both an increase in the quality of the work force and a driving force increasing the pool of highly educated engineers. Both of these effects are missed because it was not possible to account for these students.

Internal Training Programs

Very little is known about the extent of in-house education. Except for the possible additional value of the degree credential, continuing education through credit courses offers no more advantages than does internal training. Indeed, internal training often includes credit courses delivered at the job site, either in person or electronically. No appraisal of human capital in the engineering community can ignore the potential of retraining. Whenever a new engineering or technician position is created, the employer has a decision to make. He can "buy one" from an engineering school or "make one" from a known supply of raw material, a displaced or underutilized person in his own organization. The cost, time required, and effectiveness of either alternative are the factors that must be considered.

Mobility

The weekly parade of technical employment advertising in Sunday newspapers, even in slow economic periods, attests to the importance of job mobility in the employment and utilization of engineers. Within each pool, there is continual movement. Most transactions may be assumed to be an improvement or placement for an unemployed person and therefore an improvement in utilization. However, against this must be counted the cost of obtaining and training a replacement. Though not much is known about the process, it is assumed that it is a "trickle-down" effect, with several transactions taking place in series and with a new entrant eventually coming in to fill the vacancy. The high mobility of the technical work force may be a major factor in the vitality of American industry, but the panel suspects the cost in money and productivity must be very high.

Mobility is higher in certain geographical areas (e.g., Silicon Valley) than in others. The beneficial effects in terms of technology transfer must be correctly balanced by the cost and the human and family effects, as well as by the possible leakage of technical proprietary information. To the best of the panel's knowledge, no quantitative study has been made of this important social phenomenon.

NOTES

1. Simplified Model of the Engineering Infrastructure. SOURCE: 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* (Washington, D.C.: National Academy Press, 1981).
2. Hypothetical Complete Model of Technical-Labor Supply and Demand (Schematic). SOURCE: Gregory A. Jackson and Robert W. Meuller, Jr. *On Projection of Jobs for Scientists and Engineers*. Prepared for the Commission on Human Resources, National Research Council. Harvard University, December 1981.
3. Supply/Demand and Model for Engineers. SOURCE: Robert P. Stambaugh, "Engineering Manpower Needs of Industry." Presented at the Symposium on Engineering Manpower and Education Needs of the 1980's, Annual Meeting of the American Association for the Advancement of Science, Washington, D.C., January 1982.
4. Occupational Labor Market Flows. SOURCE: National Science Foundation. *Science and Engineering Personnel: A National Overview*. NSF 80-316 (Washington, D.C.: NSF, 1980).
5. Projected Engineering Manpower Transactions, Figure 1. SOURCE: William P. Upthegrove, *Engineering Manpower and Education: Foundation for Future Competitiveness* (Washington, D.C.: Business-Higher Education Forum, October 1982).
6. Chart II-1 Schematic; C Diagram of the Science and Engineers DauffenBach/ Fiorito/Folk Labor Supply Model. SOURCE: Robert C. DauffenBach and lack Fiorito, *Projections of Supply of Scientists and Engineers to Meet Defense and Nondefense Requirements, 1981–87: A Report to the National Science Foundation*. Contract No. SRS-8210548 (Stillwater: Oklahoma State University, April 1983).
7. Committee on the Education and Utilization of the Engineer. *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future* (Washington, D.C.: National Academy Press, 1985).
8. Panel on Engineering Employment Characteristics. *Engineering Employment Characteristics* (Washington, D.C.: National Academy Press, 1985); Panel on Engineering in Society. *Engineering in Society* (Washington, D.C.: National Academy Press, 1985).
9. Office of Scientific and Engineering Personnel, National Research Council. *Labor-Market Conditions for Engineers: Is There a Shortage? Proceedings of a Symposium* (Washington, D.C.: National Academy Press, 1984).
10. National Science Board. *Science Indicators* (Washington, D.C.: National Science Foundation, published biennially).

11. Panel on Engineering Graduate Education and Research. *Engineering Graduate Education and Research* (Washington, D.C.: National Academy Press, 1985).

12. National Research Council. *Summary Report 1982: Doctorate Recipients From United States Universities* (Washington, D.C.: National Academy Press, 1983).

13. *Engineering in Society* (see note 8 above).

14. Engineering Manpower Commission. *1983 Engineering and Technology Degrees* (New York: EMC, 1984).

15. National Science Foundation. *U.S. Scientists and Engineers: 1982*. NSF 84-321 (Washington, D.C.: NSF, 1984).

4

Modeling

NEED FOR AND USE OF MODELS

When attempting to understand interactions within a complex system, it is frequently useful to construct one or more simplified representations of the system under study. These models may address only one aspect of the problem, or they may reflect only its structure. Models of this type, although limited in capability, are useful because they offer controlled "what if" capability, insight into critical relationships, evaluation of assumptions, and a low-cost study environment.

In creating a model, many simplifying assumptions must be made, and the available data must be critiqued, compared, and consolidated. These two interrelated activities focus the attention of the investigators on the more fundamental aspects of the problem being studied. Certainly they force attention toward the measurable attributes of the problem. The adequacy of available data reflects the broad consensus viewpoint and the definition of historically significant variables.

CRITIQUE OF EXISTING MODELS

A large number of models and studies have been made of various aspects of engineering manpower. These may be classified in two general categories—supply and demand. On the supply side, for example, it has been shown that disciplines chosen by students are influenced by future job outlooks. On the demand side, future job openings are related to the pattern of economic growth. These are but two examples chosen from literally hundreds of papers and books.

More recent studies employ more elegant methods. In no small part this reflects the availability of better-quality data from a diverse set of sources including the National Science Foundation (NSF), the Bureau of Labor Statistics (BLS), and the Engineering Manpower Commission (EMC). Specific models are described in the proceedings of the Symposium on Labor-Market Conditions for Engineers sponsored by the National Research Council.[1]

Although many of the prior studies improve our understanding of what has occurred relative to the flow of graduates from the education arena to the workplace, we know painfully little about the "Why's" behind this movement—Why is a curriculum chosen? Why is one job accepted while another goes begging? Why do people move between the government, business, and education sectors? And so on. An additional complication in modeling is that it takes three or more years for the supply of newly graduated engineers to adjust to changes in demand. This can also be complicated by cyclical overcorrections.

DEVELOPING THE CEUE SIMULATION MODEL

The Panel on Infrastructure Diagramming and Modeling found that existing models did not describe the engineering community in sufficient detail to analyze the flows described in the flow diagram discussed in Chapter 3. The panel anticipates that the NSF model will serve that purpose in the long term. However, the panel decided to develop an interim simulation model—referred to here as the CEUE* model—as an aid in analyzing flows for the purpose of this study.

Model Objectives

A very restricted but still interesting and challenging set of objectives was chosen for the CEUE model described here. The panel first concentrated on the flow of the population-to-education-to-job-market supply. (This emphasis was chosen because it was consistent with the flow diagram responsibility of the panel.) Second, the model was limited to a relatively high summary level because of the limitations of the available data and in order to ease the calibration and maintenance problems. Thus, the CEUE model does not give detail on engineering disciplines. Third, it was decided to study only the flows of people who

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* CEUE = Committee on the Education and Utilization of the Engineer.

have received their formal education in engineering and scientific disciplines. Finally, the model runs in an open loop mode, which allows easier interaction and model formulation but obscures unsuspected feedback phenomena. The panel suspects that an upper bound on engineering enrollment will occur during the early 1990s because of a shortfall in new Ph.D.s choosing to teach in engineering. This remains only a supposition at this time, because the number of students was not limited by the number of anticipated trained and working teachers. Thus, it was assumed that there would be a significant improvement in teaching productivity over the next 20 years. It is recognized that the model is based on the size and flows among the several populations and does not directly consider economic and political forces that may influence allocation of resources and thus size and flows among the various population pools. However, dependable data are not available to directly relate the size and flows of population pools in the engineering community to economic factors. Rather, the size of pools and flows themselves represents the effects of economic, political, and social factors.

In summary, the CEUE model can simulate the flow of engineers in the United States beginning in 1950. It is possible to run alternative cases, thus giving relatively crude forecasts of the supply of engineers to the work force.

Program Features

The CEUE simulation model[2] was written to run on the IBM Personal Computer (PC). Basically, the program has two main parts: historical and forecasting. The historical module uses historical data obtained from many sources and produces on the color monitor graphic representations of these data. There are also various options available for the user that permit trend analysis. These options are invoked from a user-friendly menu. For example, pressing a function key on the PC keyboard results in the production of a graph on the color monitor. Also, with a graphic printer, a user can obtain a hard copy of the result.

The forecasting module predicts the results listed below based on population distribution and growth. The program starts with an initial formulation of the population data, which are obtained from various historical sources. Then it forecasts the following:

- the population distribution (this includes males and females, ranging in age from 1 to 100);
- high school graduates;

- first-year enrollment in colleges;
- bachelor's degrees in engineering, physical science, mathematics, and computer science;
- M.S. graduates in the aforementioned fields;
- Ph.D. graduates in the aforementioned fields (the graduates are divided into classes: males, females, and U.S. citizens and foreign nationals); and
- the engineering work force, in different fields, and by different employers.

The forecasting module is also menu-driven and, like the historical module, uses function keys to choose options. The forecasting module first computes the results and then asks the user whether he or she wants to view printed answers on the monochrome monitor or plotted answers on the color graphics monitor. For example, a graph can be displayed that shows the decline in the number of the high school graduates starting in the early 1980s and extending through the mid-1990s. This downward trend affects the number of B.S., M.S., and Ph.D. graduates in the different fields. The time delays between B.S., M.S., and Ph.D. degrees are evident from the displayed graph.

Finally, the model has a "what if" option. For example, a hypothetical case can be presented in which the graduation rates of females and foreign nationals are used as parameters to analyze the impact their potential increased enrollment might have on the declining supply of engineering graduates.

RESULTS, SELF-CRITIQUE, AND LIKELY EXTENSIONS

The total U.S. population by age and sex provides the basis for estimating the number of individuals reaching college entry age. Projected values of the key variables used in this simulation model are generally based on the naive assumption of no future changes in their value. However, the population projections reflect the declining birth rates that were experienced beginning in the late 1950s and continuing to the present time.[3]

Based on these population projections, a steady decline in the future annual 18-year-old cohorts to about 75 percent of current numbers could result in a decline in the number of future engineering graduates. This decline could be offset by factors associated with increases in the number of students choosing engineering. For example, historical data indicate that 4 to 6 percent of male high school graduates have pursued engineering degrees. The panel estimates that an increase in the rate approaching the higher range could offset the overall decline in student population.

The CEUE model offers an opportunity to evaluate data on women and to assess the implications of their growing participation in engineering (see Figure 7). The rapidly increasing female participation in computer-related disciplines is a likely harbinger of similar trends in engineering. A number of the more mathematically based engineering disciplines already indicate a meaningful increase in female participation. Overall, the percentage of female engineering graduates increased by a factor of 10 during the 1970s. Changes in minority participation can be sized by changing overall participation rates. However, the historical data have not been included at this time.

The model can also analyze the effects of the increasing percentage of engineering doctoral graduates who are foreign-born. Today these foreign-born graduates are approaching 50 percent of the number of Ph.D.s produced by universities. It is interesting to note that this effect is largely the result of a significant decrease in the number of U.S.-born students continuing beyond the master's level.

The model can also evaluate the replacement rate for engineering Ph.D.s working in the education sector. Even if the current supply of new engineering faculty were adequate, our universities are expected

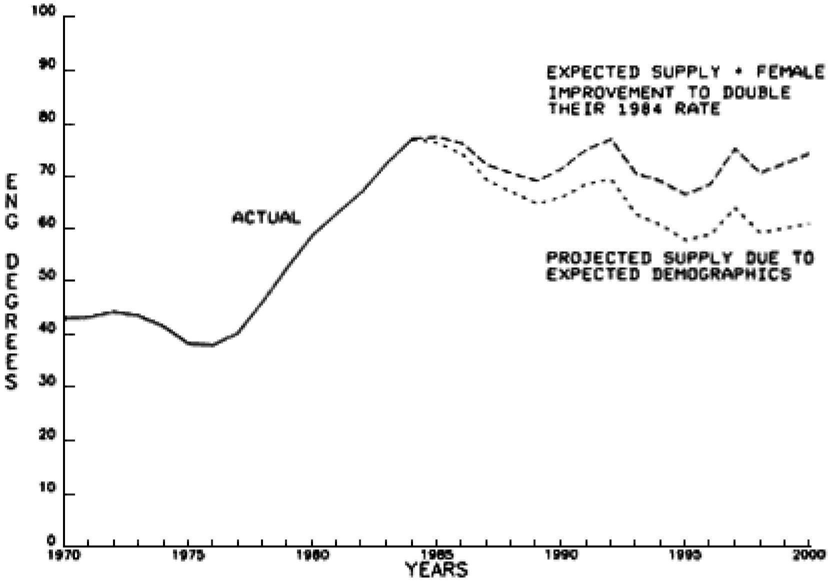

Figure 7
B.S. engineering supply (CEUE Model).

to face an increasing demand for new faculty to replace the growing number of current faculty who will be retiring during the next 15 years. On a discipline-by-discipline basis, this mismatch may be even more serious.

The model does not produce projections with narrow confidence bands. For example, using the actual 1950 statistics as of 1950 and projecting for 30 years gives actual-to-projection ratios of 50 to 100 percent. Almost all variables changed by 25 percent or more over the period, and many moved by a factor of 2. Thus, exercising the CEUE model with the naive assumptions described earlier would be inadequate for many purposes regardless of how refined or detailed the model was. On the other hand, isolation of the variable for which model results are particularly sensitive enables the model to offer constructive direction to those guiding future causal studies and to those seeking new education policies.

NOTES

1. Office of Scientific and Engineering Personnel, National Research Council. *Labor-Market Conditions for Engineers: Is There a Shortage? Proceedings of a Symposium*. (Washington, D.C.: National Academy Press, 1984).
2. Detailed data on the model and its structure and sample runs are available on request from the Office of Scientific and Engineering Personnel, National Research Council, 2101 Constitution Ave., N.W., Washington, D.C. 20418.
3. Note, however, that even though the methodology is sound, birth rate patterns have shifted drastically over the past three decades, and the model will merely reflect our current estimate of future birth rates. For present purposes this is of little importance, since all new entries into the engineering work force during this century have already been born.

5

Data Bases

This chapter provides an overview and assessment of the data bases used in the development of the panel's flow diagram and its CEUE model. Fourteen distinct data bases were used to obtain the necessary data and estimates on the education and employment of those in the engineering community. The panel also made use of a large variety of secondary sources that are not reviewed here. The chapter is divided into four parts: an overview, a discussion of data coverage, a technical assessment, and recommendations.

OVERVIEW OF DATA BASES

Table 1 summarizes the main features of the 14 data bases used in developing the panel's flow diagram and model. The features summarized in the table are discussed below.

Data Base Manager

The term *data base manager* refers to the organization that is principally responsible for storing and reporting the data. The National Science Foundation (NSF), National Research Council, Engineering Manpower Commission (EMC), Bureau of the Census [Census), Bureau of Labor Statistics (BLS), and National Center for Education Statistics (NCES) are the primary data base managers. There is, however, a considerable level of interdependence among the data base man

TABLE 1 Overview of Existing Engineering Data Bases

Data Base[a]	Data Base Manager	Data Collection Method	Respondent	Focus	Frequency	Time Period	Availability
Census	Bureau of the Census, Department of Commerce	Mail survey	Household	Personal, education, employment	Every 10 years	1790–1980	Special computer tapes; vary according to sample
Postcensal Manpower Survey (PMS)	National Science Foundation (NSF)	Mail survey	Individual	Personal, education, employment	Every 10 years	1962, 1972	Computer tapes, detailed tabulations
National Survey of Experienced Scientists and Engineers (ESE)	NSF	Mail survey	Individual scientists, engineers	Personal, education, employment	Biennial for 6 years after census	1974, 1976, 1978	Computer tapes, detailed tabulations
Survey of Recent Science and Engineering Graduates (RSE)	NSF	Mail survey with limited telephone interview follow-up	Recent BS/MS graduates in science and engineering	Personal, education, employment	Biennial	1971–1981	Computer tapes, detailed tabulations

Data Base[a]	Data Base Manager	Data Collection Method	Respondent	Focus	Frequency	Time Period	Availability
Survey of Earned Doctorates (ED)	National Research Council	Mail survey	Individual doctorate recipient	Personal, education	Annual	1958–1988	Part of Doctorate Record File tape, detailed tabulations
Survey of Doctorate Recipients (DR) File	National Research Council	Mail survey	Individual doctorate recipient	Personal, education, employment	Biennial	1973–1983	Part of Doctorate Record File tape, detailed tabulations
Current Population Survey (CPS)	Bureau of Labor Statistics	Structured interview	Household	Personal, employment	Monthly	1942–1980	Special tapes, limited tabulations
Occupational Employment Survey (OES)	Bureau of Labor Statistics	Mail survey	Employment establishment	Employment	Periodic 3-year cycle for different groups of industries	1971–1983	Tapes, limited tabulations
Engineering and Technology Degrees Granted (E/T Degrees)	Engineering Manpower Commission (EMC)	Mail survey	Educational institution	Education	Annual	1966–1983	Tabulations
Engineering and Technology Enrollments (E/T Enrollments)	EMC	Mail survey	Educational institution	Education	Annual	1966–1983	Tabulations

Data Base[a]	Data Base Manager	Data Collection Method	Respondent	Focus	Frequency	Time Period	Availability
Professional Income of Engineers (PIE)	EMC	Mail survey	Employment establishment	Education, employment	Annual (since 1980)	1953–1983	Tabulations
National Survey of Compensation (Battelle)	Battelle	Mail survey	Employment establishment	Education, employment	Annual		Tabulations
Professional Engineer Income and Salary Survey (PE)	National Survey of Professional Engineers	Mail survey	Individual members	Education, employment	Annual (since 1980)	1963–1983	Tabulations
Fall Enrollment Compliance Report of Institutions of Higher Education (Fall Enrollment)	Department of Education	Mail survey	Education institution	Personal, education	Annual	1966–1983	Tabulations

[a] Data bases are referred to in the text of this report by the acronym or short form in parentheses following the title of the data base.

agers. For example, NSF and BLS both rely on the census for some of their samples and the actual administration and compilation of the surveys. NSF, in turn, operates as a funding or sponsoring body for the Research Council.

The significance of the interrelationships among the data base managers stems from the increased likelihood that the individual data bases could be made fully compatible with each other at some time in the future. NSF acts as the primary integrative organization particularly by standardizing key survey questions and by sponsoring a mathematical model that combines a number of its data bases.

At the present time, however, the variety of data base managers increases the difficulties associated with integrating the individual data bases. Each data base is constructed to address the issues that follow from immediate organizational purposes of the data base manager. Thus, NSF focuses heavily on the training of scientists and engineers, on the functioning of higher education, and on the types of employment of scientists and engineers. By contrast, BLS focuses exclusively on *where* scientists and engineers are employed. One major consequence of these differences is that definitions of engineer and engineering differ. As a result, there are marked discrepancies in the estimates of the number of engineers derived from different sources using different definitions. (For example, estimates in the number of engineers practicing in the United States range from 1.2 million to 1.9 million.)

Data Collection Methods

Mail surveys are the primary means used by the 14 data bases (listed in Table 1) for collecting data. Only the Current Population Survey (CPS) consistently uses an interview method. Mail surveys are the most cost-effective method for collecting the data, and, given the relatively high existing response rates to the mail surveys (see section on "Respondents" below), there is little reason for changing data collection methods. Studies conducted by the Census indicate that mail surveys do not in themselves result in biased or inaccurate data.

Respondents

Respondents to data base surveys fall into three categories: (1) the targeted individual, (2) the household in which the targeted individual resides, and (3) the establishments where the individual works or is educated. NSF, Research Council, and National Society of Professional

Engineers (NSPE) surveys are directed at the targeted individual, EMC surveys at the employment establishment or educational institution, and the Census surveys and CPS at the head of the household. BLS and NCES direct certain surveys to establishments and other surveys to individuals. Battelle's survey is sent to both individuals and establishments at the same time.

The choice of respondent affects key aspects of the data collection and analysis effort. Individuals and households are more willing to provide more detailed information than is an establishment. Establishment surveys are therefore generally designed to collect limited amounts of information on a relatively few categories (e.g., occupation and industry). The unit of analysis is generally a group of individuals rather than an individual. As a result, it is possible to generate data on "males" or "Asiatics" but seldom "male Asiatics" without adding enormously to the reporting burdens of an organization. If the number of categories on an establishment survey is large or if the survey uses unfamiliar categories, it becomes more probable that the data will be less reliable. At this time, despite the use of establishment data to project manpower needs and opportunities, hardly any published research exists on the accuracy of establishment surveys.[1]

Considerably more detail can be obtained from individual respondents, but there remains the concern that individuals may selectively distort their responses, particularly in status-related areas such as degrees, salary, occupation, and organizational level. Although the research is limited, Census research studies tend to indicate that while errors in reporting do occur, they are not major and there is no consistent pattern of bias.

Similar concerns exist for household surveys, with the added issue that the person answering the survey may have little idea about what other members of the household actually do or earn and what their educational backgrounds are. As is the case with establishment surveys, there is little research to support or refute this issue.

Data for the panel's flow diagram and the CEUE model were developed from surveys of individuals. Although establishment data can be used to estimate the size of the various stocks, the level of detail required for an analysis of flows requires that data be collected on individuals. As a result, the most useful data bases are those in which the respondent is an individual or household.

Target Population

The term *target population* refers to the group of individuals on whom data are sought. Some target populations are very broadly defined (e.g., by Census, CPS, and the Occupational Employment Survey (OES)); others are very narrowly defined (e.g., Survey of Doctorate Recipients (DR), Survey of Recent Science and Engineering Graduates (RSE)). For example, DR only provides information on engineers with doctorates, and RSE only provides information on engineers and computer specialists who have graduated with bachelor's or master's degrees.

The flow diagram and model require personal, educational, and employment information on three specific occupational groups: engineers, computer specialists, and technicians. A number of the data bases only address a distinct segment of these populations.

Overall, the data bases as currently configured do not provide detailed up-to-date information on engineers and computer specialists without degrees, associate degree engineers, and computer specialists and technicians. Some information is available from Census, CPS, and the Postcensal Manpower Survey (PMS), but in the case of Census and PMS, it is provided only once every 10 years. The CPS data base is constructed on a relatively small sample size.

The absence of data in these areas in part reflects the differences in the definitions of engineers and engineering that underlie the various data collection efforts. Attention has been focused principally on a primary segment of the engineering community, the engineer with a degree (B.S. or above). Yet NSF and other bodies acknowledge that industry frequently meets local shortages of B.S. engineers by upgrading other technical staff, many of whom have no degrees.

Other small but significant segments of the engineering community also receive little attention. Military personnel with B.S. degrees or equivalent training in engineering and individuals with computer specialties are not treated as part of the general labor force. For example, the BLS labor participation rate is calculated after excluding those in military service. This figure is relatively large: in 1979–1980, 2.1 percent of the graduating class in engineering entered the armed forces.[2] In addition, a significant percentage of physical science graduates also entered the armed forces as engineers.

The inability to obtain complete coverage of the engineering community using the existing data bases means that the data elements in the flow diagram tend to underestimate the size of the stocks and flows.

Focus

As mentioned earlier, the focus or purpose of each data base varies but can be captured in a combination of three categories: personal, education, and employment. Establishment surveys tend to focus on a single category, while individual surveys cover two or more categories. The precise coverage of the different data bases is explained in more detail below (see section on "Data Base Coverage").

Frequency

The frequency with which a data base is updated is a function of its purpose and complexity and of the pace at which the statistics change. For example, the size and scope of the census ensures that its frequency remains low. By comparison, the need to adjust salaries in inflationary periods resulted in an increase in the frequency of various salary surveys, such as the Professional Engineer Income and Salary Survey (PE).

The frequency of updating the data bases listed in Table 1 varies from 1 month (CPS) to 10 years (Census and PMS). The majority of the surveys are conducted on an annual or biennial basis.

NSF's National Survey of Experienced Scientists and Engineers (ESE) is unique among the surveys. It was designed to follow the careers of a sample of scientists and engineers over an eight-year period (1970–1978). ESE provides the only genuine measure of the flow of engineers throughout the engineering community.

Time Period Covered

Some of the data bases cover long periods of time, such as those of the Census, CPS, and Professional Income of Engineers (PIE). The majority of the data bases were started in the 1960s, in part as a response to the Sputnik challenge and the subsequent increased demand for scientists and engineers in aerospace and defense industries. As a result, few of the current data bases go back to 1960. In part, the new data bases replaced others, such as the Engineering Register, but major differences in target populations and survey items severely limit the usefulness of the earlier data bases. The first year in which the data elements conform to the needs of the flow diagram as presently structured is 1962.

Availability

All of the data bases listed in Table 1 are computerized. In most cases, the data tapes are available to the public. However, in a number of instances (e.g., EMC and NCES), the existing tabulations are exhaustive enough to make the tapes redundant for most users.

The majority of the panel's work was done using existing tabulations, with the notable exception of NSF's data (PMS, ESE, and RSE).

While the quality of reporting of the data in tabular form was in general very high, serious difficulties were encountered in the use of NSF's RSE tapes. For example, on the 1979 RSE tape documentation 12,285 cases are listed, yet only 11,543 appear on the tape. More critical was an apparent difficulty in attaching the correct weights to individual cases in the 1976, 1978, and 1979 tapes. (For 1979 data approximately 5 percent of the cases have incorrect weights.) This problem made it impossible to reconstruct and validate NSF published tables. If they have not been addressed already, these technical issues need to be resolved by NSF.

DATA BASE COVERAGE

Table 2 summarizes in detail the data elements covered by the data bases. The data elements fall into three categories: personal, education, and employment. The table provides only a limited indication of the adequacy of the data bases. There is a need not only to determine whether a specific topic is covered but for what period of time, in what detail, the underlying unit of analysis, and the representativeness of the sample. Each of these issues is addressed below in terms of the requirements of the flow diagram.

Personal Variables

The six establishment-respondent surveys (see Table 1) provide no personal background data. The remaining surveys with the exception of OES provide standard information on age, sex, and marital status (see Table 2).

Prior to 1972 the surveys did not include items on racial or ethnic background with the exception of the census. For the PMS and ESE data bases, NSF used the individual's census response to cover this variable. The census and PMS responses of individuals in the ESE sample are used in the ESE data base. Citizenship is included in the individual respondent data bases except for CPS and OES. Total income, as opposed to base pay from a primary source of employment, is asked in some surveys (Census, PMS, CPS, and DR) but not in others (ESE, RSE, OES, and the Survey of Earned Doctorates (ED)).

Education

The PMS, ESE, RSE, and ED generate considerable data on types and level of education. However, the range of postsecondary education cov

TABLE 2 Data Elements in Existing Data Bases

Data Elements	Census	Postcensal Manpower Survey (PMS)	National Survey of Experienced Scientists and Engineers (ESE)	Survey of Recent Science and Engineering Graduates (RSE)	Current Population Survey (CPS)	Occupational Employment Survey (OES)
Personal						
Age	X	X	X	X	X	—
Sex	X	X	X	X	X	—
Race	X	—	—	X	X	—
Marital status	X	X	X	X	X	—
Citizenship	X	X	X	X	—	—
Income	X	X	—	—	X	—
Education						
Level	X	X	X	X	X	—
Field	X	X	X	X	—	—
History	—	X	—	X	—	—
Type of degree	—	X	X	X	—	—
Field	—	X	X	X	—	—
Date received	—	X	X	X	—	—
Date enrolled	—	X	X	—	—	—
Current status	—	X	X	X	—	—
Other training	—	X	X	—	—	—
Future plans	—	—	—	—	—	—
Source of support	—	X	—	X	—	—
Employment						
Employment status	X	X	X	X	X	—
Current job						
Occupation	X	X	X	X	X	X
Type of employer	X	X	X	X	X	X
Industry	X	X	X	—	X	X
Level	—	X	—	—	—	—
Tenure	—	X	—	—	—	—
Work activities	X	X	X	X	—	—
Salary	X	X	X	X	X	—
Satisfaction	—	X	X	—	—	—
Skill utilization	—	—	X	X	—	—
Job history						
Occupation	—	X	X	—	—	—
Type of employer	—	X	X	—	—	—
Industry	—	X	X	—	—	—
Level	—	X	—	—	—	—
Tenure	—	X	—	—	—	—
Work activities	—	X	X	—	—	—
Salary	—	X	X	—	—	—
Satisfaction	—	X	X	—	—	—
Skill utilization	—	—	X	—	—	—

Survey of Earned Doctorates (ED)	Survey of Doctorage Recipients (DR)	Engineering and Technology Degrees Granted (E/T Degrees)	Engineering and Technology Enrollments (E/T Enrollments)	Professional Income of Engineers (PIE)	National Survey of Compensation (Battelle)	Professional Engineer Income and Salary Survey (PE)
X	X	—	—	—	—	—
X	—	—	—	—	—	—
X	X	—	—	—	—	—
X	X	—	—	—	—	—
X	X	—	—	—	—	—
—	X	—	—	—	—	—
X	X	X	X	X	X	X
X	X	X	X	—	X	X
—	—	—	—	—	—	—
X	—	X	—	—	—	—
X	—	X	—	—	—	—
X	—	X	—	—	—	—
X	—	—	—	—	—	—
—	—	X	X	—	—	—
—	—	—	—	—	—	—
X	—	—	—	—	—	—
X	—	—	—	—	—	—
—	X	—	—	—	—	—
—	—	—	—	—	X	X
—	X	—	—	X	X	X
—	—	—	—	X	X	X
—	X	—	—	—	X	X
—	—	—	—	—	—	—
—	X	—	—	X	X	X
—	X	—	—	X	X	X
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
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—	—	—	—	—	—	—

ered in RSE and ED are narrowly defined by their target populations—those in engineering with at least a bachelor's degree. The PMS and the related ESE are the primary sources of data on engineers and technicians with less than a bachelor's degree. Again, this is a major shortcoming in the coverage of the existing data bases, since a significant percentage of the engineers and almost all technicians come from less than four-year programs. For example, in 1972 NSF estimated that 11.3 percent[3] of engineers had less than a bachelor's degree (the Bureau of the Census estimated 30.7 percent[4]). In 1980, NSF estimated that 4.0 percent[5] of engineers had less than a bachelor's degree. This decline from 1972 to 1980 reflects a failure to account for those individuals entering engineering with less than a bachelor's degree during the 1970s.

In terms of the panel's flow diagram and model, the data bases provide limited information on the flows of individuals among fields, particularly at four-year colleges and universities. The EMC Engineering and Technology Enrollment (E/T Enrollment) data provide some aggregate information on the size of classes for each specialty within engineering, but it is impossible to determine where students switching out of engineering go and where students entering engineering come from. NCES and other sources of educational data are primarily establishment data and provide no insight into the movement of students among fields. The potential importance of the issue can be illustrated using EMC E/T enrollment and degree data: Of 110,000 full-time freshmen in engineering in 1980, 87,500 became full-time sophomores in engineering in 1981. This suggests a dropout rate or change in major of 20 percent. Of more interest is that in the class of 1982 there were 95,800 entering full-time engineering students, 78,600 sophomores, then 80,000 juniors, 92,400 seniors, and, finally, 67,000 graduates in 1982.[6]

These data raise a series of questions, not the least of which is the source of the additional 12,400 seniors in engineering and the fate of the 25,400 engineering majors who did not graduate. The latter represent approximately 38 percent of the 1982 baccalaureate engineering population.[7] The lack of clarity around these flows increases the difficulty of constructing the flow diagram.

Another difficulty with the educational data elements stems from the failure of the current status item in the RSE to distinguish between graduate students enrolled in master's and doctoral programs and to indicate the field of the program. Given the infrequency of the PMS, the RSE is critical in determining the flows of baccalaureates in engineer ing, science, and other fields into master's and doctoral programs in engineering and other fields. The same problem is encountered when using NCES fall enrollment data. The flows can only be approximately estimated from total enrollment figures.

Current data on the flow of students from high school into colleges and universities are basically limited to establishment data on the numbers of high school graduates. Very little information is available on which institutions and programs high school graduates select. The American Freshmen study provides the only measure of program choices.

Employment

Two surveys, PMS and ESE, provide almost complete coverage of the employment data needed for the flow diagram and model. Unfortunately, as noted earlier, these data bases only provide a current picture of employment patterns in the engineering community every 10 years.

The main means for updating the PMS data are the RSE and DR. While these two data bases are largely compatible with the PMS and ESE and provide considerable information about work activities and salary, they do not provide any information on type of industry. This in itself is not critical for the flow diagram and model at their highest level of aggregation, but given NSF's estimate that 78.2 percent[8] of employed engineers work in private industry, it would be useful to determine the differences among the various industrial sectors and to see where new Ph.D.s are going. The 1982 PMS and Census will provide more current information when they become available on public use computer tapes.

The job history data available from the PMS and the mobility data derived from the ESE provide the only means of estimating the flow of engineers between work activities, specialties, and occupations.

The OES and CPS provide limited data on occupations and industry. The structure of the OES data limits their usefulness with regard to the model and flow diagram, although they provide a cross-check on the representativeness of the PMS and ESE data. Similarly, the Professional Engineer Income and Salary Survey (PE) provides for checking the representativeness of the NSF data despite the sample's being limited to National Society of Professional Engineers members. The Battelle data can serve a similar function, but here the population is even more limited since only R&D establishments are surveyed.

In sum, the PMS and ESE data bases provide a reasonable amount of data on the employment of engineers. The others are of limited usefulness, although they can be used to verify estimates derived from the PMS and ESE.

Table 3 is a summary evaluation of the data bases. The PMS and ESE provide the most complete coverage. However, no data base currently available adequately covers the flow of high school students into colleges and universities. Nor is there sufficient coverage of the flows of students across the fields within the higher-education system. Finally, although the PMS and ESE provide detailed coverage of the remaining data elements, the data are only collected every 10 years and need to be augmented on a more frequent and representative basis using the NSF model to generate the needed estimates for updating. The RSE and DR data bases are deficient in item coverage, and the associate and nondegreed segment of the engineering community is not covered.

TECHNICAL CHARACTERISTICS

Table 4 summarizes and reviews a number of the key technical characteristics of the data bases, which are discussed below. This section also addresses the possibility of creating an integrated data base.

Sampling Frame

The sampling frames used for the different data bases are generally well defined in the sense that the target population is clearly identified and a listing of potential respondents can be constructed. For example, the Postcensal Manpower Survey (PMS) uses a clearly identified subset of the census population as its target population, and the Engineering Manpower Commission (EMC) has a complete list of colleges and universities offering bachelor's degrees in engineering. In a few instances, the sampling frame is either ill-defined or incomplete. For example, EMC does not have an exhaustive list of colleges and universities offering less than bachelor's-level degrees and programs in engineering. Also, EMC's salary survey has no clearly identified target population although NSPE does, namely, its own membership.

Even though a sampling frame may be well defined it may not be representative of the desired target population. For example, National Society of Professional Engineers (NSPE) membership tends to be older and better qualified than are engineers in general. Therefore, care needs to be taken in generalizing the results of this survey to the entire engineering population. For the most part, however, the sampling frames are representative of the target populations for the surveys.

TABLE 3 Data Base Coverage

Adequacy of Coverage					
	Education		Employment		
Data Base	Personal	Current	History	Current	History
Census	X	—	—	X	—
Postcensal Manpower Survey (PMS)	X	X	X	X	X
National Survey of Experienced Scientists and Engineers (ESE)	X	X	X	X	X
National Survey of Recent Science and Engineering Graduates (RSE)	X	X	X	?	—
Survey of Earned Doctorates (ED)	X	X	X	?	—
Survey of Doctorate Recipients (DR)	X	X	X	?	—
Current Population Survey (CPS)	X			?	—
Occupational Employment Survey (OES)	—	—	—	?	—

NOTE: X = fairly complete coverage; ? = some elements are covered, but there are major elements that are not covered.

Sampling Procedures

A number of the surveys are based on a "100 percent sample," and therefore, the sampling procedures are not an issue. Those data bases actually using a sample employ standard procedures to randomly select the sample. In most instances, a stratified random sample is used in order to ensure adequate coverage of key demographic, geographic, or size variables. Design effects from the stratification procedure tend to be small.

Sample Size and Sampling Fraction

The sample size and sampling fraction are the key determinants of the reliability of the subsequent population estimates. As the sample size increases and the sampling fraction increases or both, the standard error of an estimate declines. Sample sizes and sampling fractions are chosen so that the standard error for the same set of key estimates falls within certain acceptable limits. In general, the decisions concerning sample size and sampling fraction reflect a considerable amount of careful planning and analysis. While no definitive judgment can be made as to the acceptability of the sampling errors, the standard error

TABLE 4 Key Technical Characteristics of Existing Data Bases

Data Base	Sampling Frame	Sampling Procedure	Sample Size		Sampling Fraction		Response Rate		Size of Data Base		Weighting Method
			Total	Eng.	Total	Eng.	Total	Eng.	Total	Eng.	
Survey of Recent Science and Engineering Graduates (RSE)	BS/MS graduates sample of 4-year colleges and universities	1. Stratified random sample; stratified by size	9,600 (BS)	2,900 (BS)	—	—	62.7%	65.2%	6,000	1,900	Based on numbers of graduates in specific field
		2. Proportional random sample of graduates	4,300 (MS)	1,500 (MS)	—	—	56.8	54.3	2,400	800	
Census	Inventory of dwellings	Geographically stratified random sample	—	—	20%	—	100	100	13,485,000 housing units; 39,419,000 people	—	Sampling fraction
Postcensal Manpower Survey (PMS)	Individuals in 1 of 65 target occupations and individuals with 4 years or more of college in the 20 percent 1970 census sample	Stratified proportional sample; stratified by occupation, age, sex, race, by weights used in census	102,000	26,700	0.035	0.021	73.1	74.7	74,500	19,000	—
National Survey of Experienced Scientists and Engineers (ESE)	Augmented sample of PMS (1972)	Same population as PMS, but also screened for individuals meeting specific criteria	50,100	23,600	0.045	0.028	82.1	82.1	41,100	19,400	—

Survey of Earned Doctorates (ED)	All recipients of doctorates from U.S. universities	100% coverage	31,000	2,600	1.0	1.0	95.1	95.1	31,000	2,600	—
Survey of Doctorate Recipients (DR)	All recipients of doctorates from U.S. universities or doctorates working in U.S.	Stratified random sample; stratified by year of doctorate, field occupation, sex, race, size of institution, type of degree, location of institution, citizenship	65,400	3,900	0.135	0.068	62.8	56.6	39,500	2,200	Combination of sample and response weight
Current Population Survey (CPS)	Households within geographically defined primary sampling unit (PSU)	Stratified probability sample; stratified by geographic area, socioeconomic characteristics; probability defined by population size of PSU	68,500	—	0.11	—	0.96	—	65,500	—	Weighted to compensate for differential response rates and by race residence census weight (1980)
Occupational Employment Survey (OES)	Establishments covered by unemployment insurance laws	Stratified probability sample; stratified by industry and size of establishment	160,000	—	—	—	0.70	—	112,000	—	Probability of selection and nonresponse adjustment factor
			240,000	—	—	—	0.71	—	170,000	—	
			322,000	—	—	—	0.67	—	215,000	—	

data provided by NSF, the National Research Council, Census, and BLS indicate that care should be taken when using estimates of any group comprising less than 10 percent of the target population. For example, the majority of estimates on the distribution of minorities on any dimension have large standard errors, making the estimates somewhat unreliable.

Response Rate

The response rate refers to the percentage of usable responses. The majority of the data base managers expend considerable effort in ensuring an adequate response rate. Census, NSF, and the Research Council all undertake an analysis of responses to ensure that differences in response rates are not a significant source of error. As a result, the response rates achieved, while not perfect, are very high for mail surveys. In particular, the 82.1 percent response rate for the ESE in 1978 is exceptionally high, given the longitudinal design of the data base.

Results of the various analyses of responses suggest that some significant differences do exist between respondents and nonrespondents. For example, those under 30 are less likely to respond than are those 30 to 65 (71.2 percent versus 75.3 percent);[9] when sampled, engineers without college degrees are less likely to respond than are graduate engineers (68.7 percent versus 78.5 percent).[10] Engineers are less likely to respond than are physical scientists (74.7 percent versus 79.5 percent);[11] and master's-degree holders are less likely to respond than are bachelor's-degree holders (54.3 percent versus 65.2 percent for engineers).[12] These results strongly indicate that in-depth analyses of responses should continue in order to avoid additional sources of error based on response irregularities.

Accuracy of Data Base

As noted earlier, the choice of data collection method and respondent has a potential impact on the accuracy of the responses and hence on the accuracy or reliability of the data base. With the exception of the Census and the Current Population Survey (CPS), however, very little research has been done to assess the accuracy of individual responses. The data bases, therefore, may contain inaccuracies based on response inaccuracies. However, the reliability studies that have been done for the Census indicate that self-report measures of occupation and industry are moderately consistent with an employer's reports of the individ ual's occupations and industry.[13] In addition, mail survey responses are consistent with interviewer-obtained responses with regard to occupation and industry.[14]

The absence of reliability studies on the NSF and Research Council data bases, particularly with regard to the specification of the major work activity, needs to be addressed. The work activity item occurs in a more or less standard form in the NSF and Research Council data bases and is critical to the flow diagram and the CEUE model. The sheer complexity of the question and the ambiguity of many of the response categories suggest that some effort needs to be made to check the accuracy and validity of responses.

Data Compatibility

The Panel on Infrastructure Diagramming and Modeling considered the feasibility of creating a single data file that could be used in conjunction with the flow diagram and CEUE model to examine different assumptions and make projections. Since no single data base provides complete and up-to-date coverage, the compatibility of the different data bases needs to be assessed.

Based on their current formats, the NSF and Research Council data bases are all technically compatible, that is, they can be used to construct a single data base covering a significant number of items. The actual items that could be included in an integrated data base would be essentially limited to those in the Survey of Recent Science and Engineering Graduates (RSEJ). The integrated data base would have, therefore, considerably fewer data elements than have the PMS and ESE. NSF's current model is essentially based on such an integrated data base. A single data set, however, has not been created.

While it is possible to create an integrated data base using existing data bases, the resultant data base would have the following clear limitations:

- It would include no information on technicians.
- It would grossly underrepresent engineers with less than a bachelor's degree.
- It would have limited information on the type of current employment and no information on employment history.
- It would have little information on education outside of program completion.

Therefore, a more complete data base is clearly needed. Given the limitations in coverage of the current data bases, it would be more appropriate to consider the feasibility of developing a data base that will be more comprehensive.

CONCLUSIONS AND RECOMMENDATIONS

Existing data bases provide a limited picture of the engineering community as defined in the flow diagram and the simulation model developed as part of the study undertaken by the Committee on the Education and Utilization of the Engineer. In order to provide even a limited understanding of the stocks and flows of engineers, multiple data bases must be used. Moreover, the data from any source are extremely limited prior to 1970. In the future, therefore, a more complete understanding of the engineering community—or of any other technical occupation for that matter—will require some significant modifications in categorizing the community from which data are collected, in the range of information gathered, and in the coordination of the various data collection efforts. The Panel on Infrastructure Diagramming and Modeling suggests that these modifications may be achieved through the following:

- *Monitoring of existing data collection efforts should be undertaken by an organization not currently involved in any specific data collection effort. The organization should have the perspective and resources to review realistically and to integrate the need for accurate and timely data on the engineering community with the data collection efforts of the various government and nongovernment agencies.*
- *Such an organization would be responsible for ensuring that future data collection efforts were guided by an agreed-upon general model of the engineering community similar to the flow diagram described in this report. The panel suggests that the National Academy of Engineering may be suited to this role of data base monitoring.*
- *At a minimum, however, future data collection efforts should be extended to cover (1) segments of the engineering community not currently covered, (2) the flow of students through the various engineering institutions, and (3) the employment category of members of the engineering community, including industry where employed.*
- *The National Science Foundation should continue its existing plans for longitudinal studies of scientific and engineering manpower. In addition, NSF should make an effort to extend the time period covered from the current eight years. One distinct possibility is to arrange for a follow-up study of the sample of engineers and scientists surveyed between 1972 and 1978.*

- *The National Science Foundation should, separately or in conjunction with the Engineering Manpower Commission, extend the survey of recent bachelor's-and master's-degree graduates to cover the placement of graduates from all major types of scientific and technical programs.*
- *If the Bureau of Labor Statistics' Occupational Employment Survey is to remain a major input in the analysis of the demand and supply of technical manpower, it is essential that an effort be made to assess the reliability and accuracy of the data.*

NOTES

1. Discussions with BLS personnel indicate that there is a strong need to undertake such research in order to determine the reliability of BLS manpower forecasts.
2. Unpublished data from 1980 Recent College Graduates Survey. Of an estimated 66,973 engineering B.S. graduates in 1979–1980, 1,419 entered the armed forces.
3. National Science Foundation, *The 1972 Scientists and Engineers Population Redefined. Vol. 1. Demographic, Educational, and Professional Characteristics*. NSF 75-313 (Washington, D.C.: NSF, 1975), Table B1, p. 42.
4. Bureau of the Census, Technical Paper 33, Table 5, p. 68.
5. National Science Foundation, *U.S. Scientists and Engineers: 1980*. NSF 82-314 (Washington, D.C.: NSF, 1982), Table B52, p. 209.
6. Engineering Manpower Commission, E/T Enrollments, 1981, p. 16; E/T Degrees, 1982, p. 14.
7. A similar pattern exists for previous years. The figures cited do not take into account part-time students or those taking a fifth year.
8. National Science Foundation, *Recent Science and Engineering Graduates: 1980.* NSF 82-313 (Washington, D.C.: NSF, 1982), Table B60, p. 244.
9. Bureau of the Census, Technical Paper No. 33, p. 146.
10. Ibid.
11. Ibid. The difference is less marked among new graduates.
12. *United States Personnel and Funding Resources for Science, Engineering, and Technology: Survey of Recent Science and Engineering Graduates, 1980* (Washington, D.C.: National Science Foundation), p. 46.
13. Bureau of the Census, *Census of Population and Housing: 1970* (Washington, D.C.: U.S. Government Printing Office), Table 3, p. 11.
14. Ibid., Table B, p. 7.

Appendixes

Appendix A

The Definition of Engineering and of Engineers in Historical Context

Donald G. Weinert

Among the most challenging tasks in the work of the Panel on Infrastructure Diagramming and Modeling was that of establishing an operable definition of engineering and engineers on which to base data collection and analysis. Indeed, such a definition was critical to the work of all the panels of the Committee on the Education and Utilization of the Engineer. The essence of the challenge was the need to reconcile the philosophical and theoretically based definitions currently propounded by scholars and some professional engineering organizations with the practical realities of the working world.

At issue is not so much what engineering work is, though its diversity and complexity certainly present definitional challenges. Rather, the central point of contention seems to be who is entitled to be called an engineer. The basis for that contention ranges from concern that unqualified practitioners might harm public health, safety, and welfare to a somewhat elitist rejection of those perceived as not holding the "proper" credentials. Among these credentials, the most often cited by those advocating more stringent theoretical definitions are graduation from an accredited engineering program and/or some type of legally recognized licensing or certification process.

A review of the historical evolution of the terms *engineer* and *engineering* used by scholars, writers, engineering academicians, and pro

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fessional engineering organizations is instructive in coming to grips with the definitional challenge.

The word *engineer* stems from the Latin *ingenium,* meaning natural talent or capacity; also, a clever invention. The words *ingenuity* and *engine* also stem from *ingenium*. In addition, the word *engine* has as now-obsolete meanings "ingenuity" and "wile." Its current meanings include "something used to effect a purpose; agent or instrument." People acting as agents or instruments to effect a purpose are quite correctly referred to as *engines* of that purpose. Thus, the current meaning of *engine* goes beyond the commonly used mechanical device or machine used for converting various forms of energy into mechanical force or motion. So, too, does the word *engineer,* which is just as close to the word *ingenuity* as it is to the word *engine*. Thus, the modern words *engineer, engineering, ingenuity,* and *engine* are all related through common ancestry, and *engineer* does not relate solely to the word *engine* in its narrower meaning of mechanical device or machine.

Unfortunately, in early usage the word *engineer* specified almost exclusively a military engineer. Tertullian appropriated the word *ingenium* in its meaning of "a clever invention" to describe a battering ram, which through usage came to apply to any kind of military engine. The words *ingeniator, ingeniarius,* and *ingegerus* all identified builders of military machines—hence the modern-day association of the word *engineer* with machines and the general use of that word in society for a variety of functions associated with machinery and mechanical equipment. The significance of this evolution is that the terms *engineer* and *engineering* have never been, nor can they ever be, the sole province of the engineering profession as we define it today.

Of course, engineering as an activity of man—manipulating nature to produce something needed or desired—has taken place since the beginning of human history and has been well documented in the literature of all ages. (The legendary Daedalus "engineered" the Cretan labyrinth and invented wings to escape.) The existence of engineering as a profession, however, is a relatively recent phenomenon. Attempts to apply formal definitions to engineering and later to the engineer parallel the emergence of a definable engineering profession.

In discussing definitions it is important to note that the words *engineer* and *nature* are etymologically related. *Ingenium* means "natural capacity or talent" and relates to the inherent nature of people and things. This acquires special significance when one studies the many definitions of engineering over time. Those definitions have consistently contained three principal elements, either explicitly or implicitly. First, they link engineering with "the forces of nature"; second, they refer to "the use or good of man"; and third, they specify or imply a special knowledge and skill relating to natural or physical phenomena. The latter element is implicit in early definitions and descriptions of engineering activity and explicit as "a knowledge of the mathematical, natural or physical sciences" in later descriptions as a recognizable body of engineering knowledge began to take form.

One of the first formal definitions of engineering was that put forward in 1828 by Thomas Tredgold in the charter of the Institution of Civil Engineering in England. Tredgold defined engineering as "the art of directing the great sources of power in nature for the use and convenience of man." That definition contains the three classic definitional elements: the "great sources of power in nature"; "use and convenience of man"; and the special knowledge and skill relating to physical and natural phenomena implied by the phrase "the art of directing the great sources. . . ." Most early definitions, and those in modern dictionaries, contain the same three elements.

In the earliest descriptions of engineering there was a perceived need, especially by engineers, to distinguish between science and engineering—to establish engineering as an activity independent of but related to science. That need was fueled in part by the desire of those engaged in engineering to achieve status as a separate and identifiable profession. Public recognition of engineers as a group distinct from scientists is found as early as 1830 when Auguste Comte in *Cours de philosophie positive* observed: "Between scientists in the strict sense of the word and the actual managers of production, there is beginning to emerge in our days an intermediate class, that of the engineers, whose particular function it is to organize the connections between theory and practice."

A compilation of the views of engineering and scientific society leaders published by the National Society of Professional Engineers (NSPE) in 1963 demonstrates the preoccupation with making the distinction between engineering and science. It also reveals consistency with earlier definitions of engineering wherever *engineering* is defined separately. It is interesting to note that while the engineering and scientific functions are well covered in the 1963 compilation, there are very few attempts at defining an engineer or a scientist except in terms of functions. Clearly, as stated by W. L. Everitt, then Dean of Engineering at the University of Illinois, "It is easier to distinguish between the 'scientific function' and the 'engineering function' than to distinguish between the man who should be called a scientist and who should be termed an engineer. Many men perform both functions, and do it very well. . . ."

As alluded to earlier, the real definitional difficulties began when the engineering profession, as represented by its leaders and the engineering societies, began to add to the traditional definitions of engineering. Most notably, they added a fourth element, as in the definition of the Engineers Council for Professional Development (ECPD), specifying that the knowledge and skill explicitly or implicitly required for engineering should be acquired by "study, experience or practice." It was then a short step to defining an engineer first in terms of the type of knowledge and skill required; second, by how it was acquired; and finally, by what type of evidence is necessary to show it had been acquired. Evidence of "study" translated to graduation from an accredited engineering program, and evidence of "experience" and "practice" are in part reflected in licensing and certification procedures. Some engineering organizations, notably NSPE, even advocate the use of licensing as a means to show evidence of study, experience and practice.

As noted above, adding the academic credential to the definition of an engineer, and, when applied, adding the practice/experience credential, have complicated the business of describing the engineering profession. Those credentials exclude many, including those with educational backgrounds in science and those without either a four-year accredited engineering degree or a license, who are nonetheless performing what has traditionally been described as an engineering function.

The emergence of the engineering technologist with a four-year Bachelor of Engineering Technology degree has exacerbated the definitional dilemma and provided further impetus in some circles for tightening definitions because of the similarities between the educational programs for the engineer and the technologist.

In the late 1970s, under the umbrella of what was then ECPD, now Accreditation Board for Engineering and Technology, many of the engineering societies participated in a comprehensive review of definitions including that of engineering, the engineer, and the engineering technologist and technician. Their report, entitled *The Engineering Team,* was approved by the ECPD Board of Directors in 1979. It contained the following definitions and explanatory notes.

Engineering

Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.

Engineer—With a strong background in mathematics, the basic physical sciences, and the engineering sciences, the engineer must be able to interrelate engineering principles with economic, social, legal, aesthetic, environmental and ethical issues, extrapolating beyond the technical domain. The engineer must be a conceptualizer, a designer, a developer, a formulator of new techniques, a producer of standards—all to help meet societal needs. The engineer must plan and predict, systematize and evaluate—must be able to judge systems and components with respect to their relation to health, safety and welfare of people and to loss of property. Innovation must be central to the engineer.

The engineer will normally have received the first professional degree from an accredited engineering program, which requires a minimum of one-half year of mathematics, beginning with differential and integral calculus. Education in engineering analysis and synthesis shall prepare the engineer to enter the profession with potential for further development in research, design, development, management, establishment of systems, and translation of concepts into realities. An engineering education is the principal route to professional licensure.

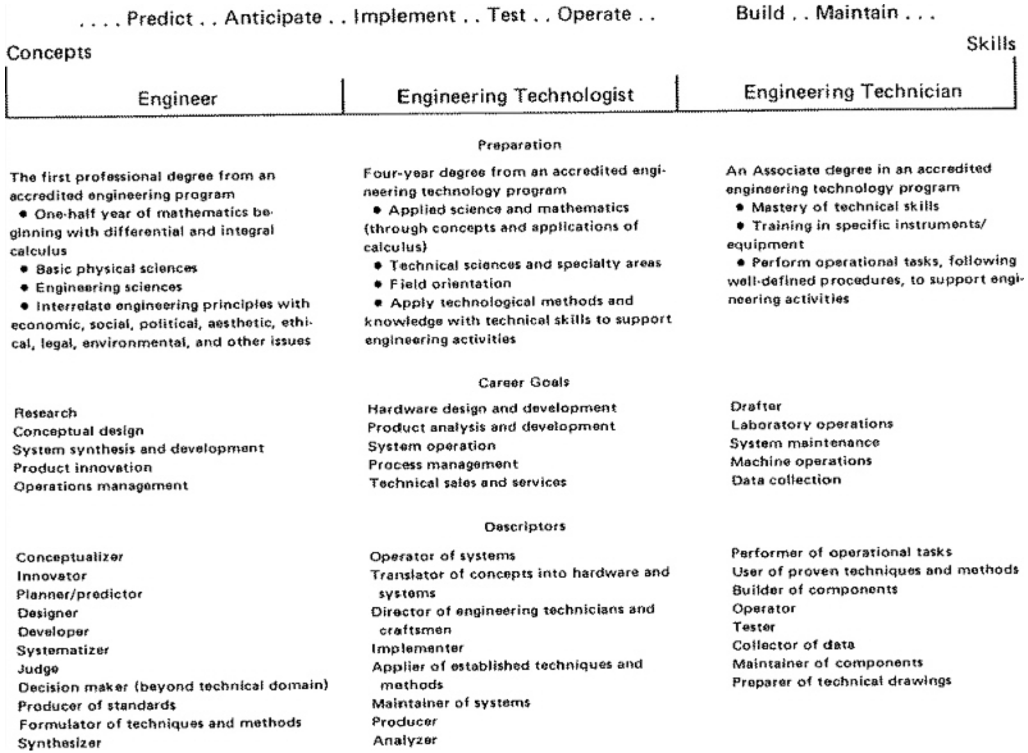
Engineering Technology

Engineering Technology is that part of the technological field which requires the application of scientific and engineering knowledge and methods combined with technical skills in support of engineering activities; it lies in the occupational spectrum between the craftsman and the engineer at the end of the spectrum closest to the engineer.

Engineering Technologist—The engineering technologist must be applications-oriented, building upon a background of applied mathematics through the concepts and applications of calculus. Based upon applied science and technology, the technologist must be able to produce practical, workable results quickly; install and operate technical systems; devise hardware from proven concepts; develop and produce products; service machines and systems; manage construction and production processes; and provide sales support for technical products and systems.

Normally, the engineering technologist will hold a 4-year degree from an accredited engineering technology program. Because of the key role as an implementer, the engineering technologist must be prepared to make independent judgments that will expedite the work without jeopardizing its effectiveness, safety or cost. And the technologist must be able to understand the components of systems and be able to operate the systems to achieve conceptual goals established by the engineer.

Engineering Technician—With a minimum of two years of post-secondary education, ideally in engineering technology, with emphasis in technical skills, the engineering technician must be a doer, a builder of components, a sampler and collector of data. The technician must be able to utilize proven techniques and methods with a minimum of direction from an engineer or an



. . . . Predict . . Anticipate . . Implement . . Test . . Operate . . Build . . Maintain . . .

Concepts — Skills

Engineer	Engineering Technologist	Engineering Technician
	Preparation	
The first professional degree from an accredited engineering program • One-half year of mathematics beginning with differential and integral calculus • Basic physical sciences • Engineering sciences • Interrelate engineering principles with economic, social, political, aesthetic, ethical, legal, environmental, and other issues	Four-year degree from an accredited engineering technology program • Applied science and mathematics (through concepts and applications of calculus) • Technical sciences and specialty areas • Field orientation • Apply technological methods and knowledge with technical skills to support engineering activities	An Associate degree in an accredited engineering technology program • Mastery of technical skills • Training in specific instruments/equipment • Perform operational tasks, following well-defined procedures, to support engineering activities
	Career Goals	
Research Conceptual design System synthesis and development Product innovation Operations management	Hardware design and development Product analysis and development System operation Process management Technical sales and services	Drafter Laboratory operations System maintenance Machine operations Data collection
	Descriptors	
Conceptualizer Innovator Planner/predictor Designer Developer Systematizer Judge Decision maker (beyond technical domain) Producer of standards Formulator of techniques and methods Synthesizer	Operator of systems Translator of concepts into hardware and systems Director of engineering technicians and craftsmen Implementer Applier of established techniques and methods Maintainer of systems Producer Analyzer	Performer of operational tasks User of proven techniques and methods Builder of components Operator Tester Collector of data Maintainer of components Preparer of technical drawings

Figure A-1
The Engineering Team. Source: Engineers' Council for Professional Development. *The Engineering Team* (New York: ECPD, 1979).

engineering technologist. He/she shall not be expected to make judgments which deviate significantly from proven procedures.

The technician should expect to conduct routine tests, present data in a reasonable format, and be able to carry out operational tasks following well-defined procedures, methods, and standards.

In addition, the 1979 ECPD report contained a matrix depicting the engineering team (see Figure A-1).

The definition of engineering in the ECPD (ABET) report remained unchanged from that first developed by ECPD in 1961 and varies little from that put forth by Tredgold in 1828 except for the addition of the "by study, experience and practice" element. However, the definitions of engineer, technologist, and technician became much more detailed, including a great deal of explanatory material. Emphasis was put on the differences in academic credentials among the three. As to function, it is clear that all three fall within the definition of engineering, albeit at different levels—hence the term *the engineering team*.

Another definition of note is that of the National Council of Engineering Examiners (NCEE) Model Law (1978 revision). Section 2 contains the following definitions:

1. *Engineer*—The term "Engineer," within the intent of this Act shall mean a person who, by reason of his special knowledge and use of the mathematical, physical and engineering sciences and the principles and methods of engineering analysis and design, acquired by engineering education and engineering experience, is qualified to practice engineering.
2. *Professional Engineer*—The term "Professional Engineer," as used in this Act, shall mean a person who has been duly registered and licensed as a Professional Engineer by the board.
3. *Engineer-in-Training*—The term "Engineer-in-Training," as used in this Act, shall mean a person who complies with the requirements for education, experience and character, and has passed an examination in the fundamental engineering subjects, as provided in this Act.
4. *Practice of Engineering*—The term "Practice of Engineering" within the intent of this Act shall mean any service or creative work, the adequate performance of which requires engineering education, training and experience in the application of special knowledge of the mathematical, physical and engineering sciences to such services or creative work as consultation, investigation, evaluation, planning and design of engineering works and systems, planning the use of land and water, teaching of advanced engineering subjects, engineering surveys and the inspection of construction for the purpose of assuring compliance with drawings and specifications; any of which embraces such services or work, either public or private, in connection with any utilities, structures, buildings, machines, equipment, processes, work systems, projects, and industrial or consumer products or equipment of a

> mechanical, electrical, hydraulic, pneumatic or thermal nature, insofar as they involve safeguarding life, health or property, and including such other professional services as may be necessary to the planning, progress and completion of any engineering services.

Quite understandably, the focus of the NCEE definitions is on qualifications and on the licensed engineer, who is referred to as the *Professional Engineer*. The definition of the *Practice of Engineering* is also substantially more detailed because it attempts to define the many types of engineering work covered by the Model Law. The introduction of the term *Professional Engineer* to describe only licensed engineers has further confused the definitional picture in that to some it implies that nonlicensed engineers may somehow be unprofessional.

Finally, confronted with the practical challenge of collecting and analyzing data, over a period of time the National Science Foundation developed eight criteria for determining who should be counted as a member of a given field of science or engineering. The criteria included those

1. who had earned a master's degree or higher in a coincident field of study and who regarded themselves, based on their total education and experience, as having a coincident profession;
2. who had earned a Ph.D. in any field of social or natural science and were employed in a coincident occupation;
3. who had earned a bachelor's degree or higher in a coincident field of study and were employed in a coincident occupation;
4. who had earned a bachelor's degree or higher in any field of study, were employed in a coincident occupation, and regarded themselves as having a coincident profession;
5. whose highest degree was in a coincident field of study at any degree level and who were employed as a college president, a college dean, or a manager or administrator of research and development, production, or operations; or who had earned a bachelor's degree or higher in a coincident field of study, were employed in a related occupation, and regarded themselves as having a coincident profession;
6. who had earned a bachelor's degree in a coincident field of study since 1969 and who regarded themselves as having a coincident profession;
7. who had earned a bachelor's degree or higher in any field of science and were employed as a college president, a college dean, or an administrator or manager of research and development, production, or operations and who regarded themselves as having a coincident profession; or

8. whose highest degree was in a related field of study and who were employed in a coincident occupation and who regarded themselves professionally to be a college president, a dean, or an administrator or manager of research and development, production, or operations.

Summing up the definitional issue, several points are clear. First, the definition of engineering is extremely broad and can accommodate a wide range of practitioners; second, that range involves level of function, area and type of practice, job titles, academic background, and experience; and third, to portray and understand the engineering enterprise in the United States adequately, all of those substantively involved in that enterprise must be accommodated in the definitional frameworks adopted, whatever the level and type of academic, experience, or practice credentials.

Appendix B

Trends in Engineering Enrollments and Degrees Granted

William K. LeBold and Patrick J. Sheridan

This report presents data on U.S. engineering enrollments and degrees from 1945 to 1983, including comparative data on all fields of U.S. four-year institutions. The primary purpose of this presentation is to provide a perspective for examining manpower trends in engineering enrollments and degrees and their impact on the U.S. engineering infrastructure.

During the past two decades, the largest single input into the U.S. engineering work force has been the engineering graduates of U.S. colleges and universities, and there is every indication that this will continue to be the case in the foreseeable future. This does not mean, of course, that other sources (such as immigration, on-the-job upgrading promotions, and military discharges) and transfers from science, technology, and other areas are not also important inputs to the U.S. engineering infrastructure. In this discussion, however, we will limit our attention to trends in U.S. engineering enrollments and in degrees awarded. More specifically, our objectives will be as follows:

- to provide information on the trends in first-year U.S. engineering enrollments and in degrees awarded since World War II (194$1$2 $3983);
- to compare trends in engineering enrollments and degrees awarded with total enrollments and degrees;

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- to examine the growth in the number and proportion of women, underrepresented minorities, and foreign nationals in first-year enrollments and in degrees awarded in engineering during the past decade (197$1$2$3983);
- to provide information on recent trends in engineering technology and industrial technology first-year enrollments and in degrees awarded; and
- to relate the trends in first-year enrollments and degrees awarded to various historical factors that may be related to those trends.

ENGINEERING AND TOTAL U.S. ENROLLMENTS AND DEGREES AWARDED

Figure B-1 and Table B-1 (pp. 88–89) provide data on the trends in first-year engineering enrollments and degrees granted from 1945 to 1984. Figure B-2 and Table B-2 (pp. 90–92) include data on first-year enrollments in all higher-educational institutions (Table B-2 only) and in four-year institutions and degrees granted in U.S. colleges and universities. To provide some insight into the relative growth rates of the various data sets, we have also indexed all enrollment and degree data using 1973 as the base (i.e., 1973 = 100 for all of the data reported). We chose 1973 because it is the earliest year for which relatively complete data are available.

In general, the data in Figure B-1 and Table B-1 indicate that first-year enrollment and bachelor's degree data in engineering have somewhat more erratic patterns of increases and decreases that tend to reflect economic and social changes, whereas the total U.S. data given in Figure B-2 and Table B-2 reflect a more stable and steady growth pattern. Both the engineering and total master's degree and doctoral degree data reflect the steady growth in graduate education that has characterized higher education during much of the past three decades. The first-year and B.S. engineering data reflect much larger fluctuations and rates of change than the M.S. or Ph.D. degree data or the total U.S. first-year enrollment and degree data. However, if these rates of change are examined using semilog scales as in Figures B-3, B-4, and B-5 (pp. 93–94), all rates of change are less dramatic and suggest more stable longrange trends. First-year engineering enrollments have been relatively steady with some decline in the late 1960s and early 1970s; they have risen since 1973. Bachelor's degrees in engineering were relatively stable in the 1950s, 1960s, and early 1970s, but they have increased slightly in the late 1970s. The master's and doctoral degrees awarded in engineering and in all fields reflect similar but significant rates of growth in the 1950s and 1960s, but they have remained relatively stable since 1970 except for a drop in doctorates from 1972 to 1979.

RECENT TRENDS BY SEX AND ETHNICITY

One of the major changes that has taken place in the past decade in engineering enrollments and degrees awarded concerns the demographic composition of the engineering student populations. These changes have been documented in Table B-3 (pp. 95–98) and Figures B-6 through B-9 (pp. 99–100). As may be noted in Table B-3, the most dramatic changes have occurred among women, with an almost 8-fold increase in first-year enrollments between 1973 and 1984, more than a 17-fold increase in the number of B.S. degrees, over a 9-fold increase in master's degrees, and more than a 3-fold increase in doctoral degrees awarded to women. The increases in underrepresented minorities (blacks, Hispanics, and American Indians) have been at slightly higher rates than the total, but these increases still represent relatively small numbers and proportions compared to the Asian-Pacific and foreign-national growth patterns. When considered collectively, the number of women, underrepresented minorities, Asian-Pacific, and foreign-national students accounts for almost one-half of the growth in first-year engineering enrollments and in bachelor's degrees awarded (U.S. majority white males account for the rest of the growth). At the master's degree level, women, Asian-Pacific, and foreign-national growth patterns have almost balanced the decline in the number of U.S. majority white male master's degree recipients. At the doctoral level, the growth in the number of degrees awarded to foreign nationals has partially compensated for the significant decline in U.S. majority white males who have been awarded the engineering doctorate in the United States in recent years.

Figures B-6 through B-9 provide a graphical insight into the relative growth of first-year engineering enrollments and the awarding of bachelor's, master's, and doctoral degrees, respectively, for women, underrepresented minorities, foreign nationals, and total engineering populations. The index is based on 1973 data (i.e., 1973 = 100). Figure B-6 indicates that the number of women and foreign nationals among first-year engineering students increased substantially between 1973 and 1984, much more than the underrepresented minorities and total groups, even though the latter more than doubled between 1973 and 1984. Figure B-7 documents the dramatic growth between 1973 and 1984 in the percentage of women awarded bachelor's degrees, as well as the significant increases in the awarding of bachelor's degrees to members of other groups. Figure B-8 maps the growth in the number of master's degrees awarded for the various groups, and Figure B-9 shows the increasing proportion of foreign nationals awarded engineering doctorates during the past decade. (See Table B-3 for the actual numbers of enrollments and degrees awarded.)

ENGINEERING TECHNOLOGY AND INDUSTRIAL TECHNOLOGY TRENDS

In recent years, engineering technology and, to a lesser degree, industrial technology have taken on increasing importance as an integral or supplementary part of the overall engineering infrastructure. This is especially true with regard to Bachelor of Engineering Technology programs that have been developed and supported by the engineering profession and accredited by the Accreditation Board for Engineering and Technology (ABET), formerly the Engineers' Council for Professional Development (ECPD). Table B-4 (pp. 101–106) provides first-year associate and bachelor's degree program enrollment data for women and ethnic minorities for both engineering technology and industrial technology programs that have at least one ABET-or ECPD-accredited program for 1972 to 1984. The table also provides comparative data for women and ethnic minorities on associate degree and Bachelor of Engineering Technology awards in engineering technology between 1973 and 1984; Table B-4 provides the same information for industrial technology programs between 1973 and 1982. These degree trends show relatively similar and significant growth patterns in the numbers of Bachelor of Engineering Technology and Bachelor of Industrial Technology awards. The number of associate degrees awarded, however, remained relatively stable over the period. It should be noted that the engineering technology and industrial technology data are probably underestimates because the data are limited to institutions with at least one ABET-accredited program, and the collection of industrial technology data was discontinued by EMC in 1982.

FACTORS INFLUENCING ENGINEERING ENROLLMENT TRENDS

A review of the events that took place between 1945 and 1984 provides some insight into the peaks and valleys in engineering enrollments and degrees (Figure B-10, p. 107). Immediately following World War II (1945), there was an unprecedented increase in U.S. college enrollments; U.S. colleges and universities readily accepted the challenge of providing opportunities for returning veterans who wished to study under the GI Bill. Engineering colleges faced especially difficult challenges and demands, because many GIs who had trained as mechanics, electronic technicians, and construction specialists were interested in an applied technical education; yet there were only a few more than 100 U.S. engineering schools.

Freshman engineering enrollments soared from under 45,000 in 1945 to over 90,000 in 1946. And because many returning veterans already had some engineering education and training prior to or during World War II, the number of engineering freshmen and B.S. degrees awarded soared well beyond the pre-World War II levels. Indeed, increasing concerns about a surplus of engineers resulted in a very rapid decline in freshman enrollments as the number of high school freshmen and the number of veterans declined between 1946 and 1950; these declines were further fueled by predictions by the U.S. Department of Labor of a surplus of engineers; engineering graduates, including veterans, experienced increasing difficulty in finding jobs around 1950. As a result, freshman enrollments declined to a post-World War II low of less than 35,000 students, although the number of B.S. degrees awarded that year reached an unprecedented high of over 50,000, many times higher than the pre-World War II levels.

In spite of the dire predictions of a surplus of engineers, the 1950s were boom times for engineers, not only in the military and related defense industries but also in civilian-related research and development. First-year engineering enrollments significantly increased, mainly because of draft deferments for engineering students during the Korean War in the early 1950s and the large numbers of returning Korean War veterans who then used the GI Bill to further their education in the mid-1950s.

In the late 1950s and early 1960s, engineering enrollments declined as U.S. engineering institutions became more selective in their choice of students. This was especially true at the land grant schools and agricultural and mechanical (A&M) colleges, which at the same time expanded their nonengineering programs. Meanwhile, U.S. colleges were preparing for the rapid increases in enrollment that were expected when the post-World War II baby boom generation came of college age. Many states and local communities created community colleges; in addition, two-year branches of four-year institutions were expanded as medium-sized communities and U.S. cities created a variety of commuter colleges and regional campuses.

Increased enrollments as a result of the baby boom and the effects of the Russian launching of Sputnik (1957) brought a number of changes to institutions of higher learning. Many four-year colleges and universities, especially state-supported institutions, not only became more selective in choosing students, but graduate enrollments and research missions provided an impetus for change in many schools. During the 1960s, increased demands for higher education and graduate study resulted in the conversion of many four-year A&M and state colleges into comprehensive universities. In 1953, American Society of Engineering Education (ASEE) Evaluation of Engineering Education Study was begun. Chaired by Dean L. E. Grinter and extending from 1953 to 1955 its participants included many of the leading deans of schools of engineering. The study originally recommended a dual undergraduate program: (1) a professional scientific program and (2) a professional general program. The latter was rejected, and most engineering institutions opted for the more prestigious engineering-science-based curriculum.

As a result of this demand for higher-quality engineering education and increased diversity in higher education, undergraduate engineering enrollments in the 1960s did not increase as rapidly as total U.S. enrollments. In fact, the number of B.S. degrees in engineering leveled off while the total number of bachelor's degrees continued to rise. Engineering graduate enrollments continued to increase as graduate programs in all fields, especially engineering doctoral programs, were given increased importance and impetus. Moreover, the demand for more education and more practical technical programs was being met by the expansion of certificates and two-year associate degree programs, and the two-year engineering technician programs offered in community colleges, regional campuses, proprietary schools, and nonprofit technical institutes. As noted earlier, these technical educational programs, coupled with the development of specialized technical training programs in the military and on-the-job programs in industry and business, created a reservoir or pool of engineering-related talent, which is frequently tapped during periods of high engineering demand and related shortages of degreed engineers. This pool is further augmented by the significant number of engineering college students who leave college with one to four years of engineering education but no degree and who frequently assume engineering-related positions. The pool also includes B.S. graduates in physical science and mathematics and foreign nationals (who enter the pool directly as engineering professionals or acquire student visas, and frequently remain in the United States in engineering positions).

The Vietnam War, the space program, the growth of the computer industry, and increased expenditures for research and development created additional demands for engineers in the mid-and late 1960s; as a result, freshman enrollments and bachelor's, master's, and doctoral degree awards increased to some degree. Graduate engineering educa tion was given a further stimulus as a result of the ASEE-sponsored Goals of Engineering Education project, which recommended the master's degree as the first professional degree for research, development, and design.

However, the end of the Vietnam War and its related student unrest, the decline in the space program, the increased national priorities given to human services and social programs, and the reported oversupply of engineers resulted in another sharp decline in freshman engineering enrollments, which reached new lows in 1971 and 1972. Many engineering colleges responded by launching new recruitment and high school relations programs.

Affirmative action and equal educational and employment opportunity programs, coupled with the women's movement and the civil rights movement, resulted in a new, accelerating interest in engineering in the mid-1970s and early 1980s. These nontraditional engineering students included women, black Americans, Hispanic Americans, and American Indians; these groups augmented the Asian-Pacific minority students who were always somewhat overrepresented in engineering and science. In addition, increasing numbers of undergraduate foreign students, especially from the developing Organization of Petroleum Exporting Countries, and graduate students from throughout the world were enrolling in U.S. engineering colleges in unprecedented numbers. Many entered directly, but others entered from community colleges, technical institutes, and other four-year colleges.

As a result of the increased interest in engineering during the mid-and late 1970s and the early 1980s, an unprecedented growth in undergraduate engineering college enrollments has occurred. About one-half of the growth has come from nontraditional students: women, underrepresented minorities (blacks, Hispanics, American Indians), and foreign nationals, but the other half has come from more traditional sources of white males and Asian-Pacific minorities. All of these groups have grown in size because of the relatively high demand for engineers and the national priorities given to engineering-related problems: energy, the environment, communications, computers, information sciences, and, more recently, national defense. Responses to these demands for engineering talent have raised the quantity and quality of both graduate and undergraduate students at most U.S. engineering schools.

However, the unprecedented recent growth in undergraduate enrollments and B.S. engineering degrees awarded and the large number of foreign nationals in engineering, combined with U.S. and world economic problems, have created new imbalances. It now appears that there is a possible oversupply of bachelor's degree engineers in some areas (civil and chemical engineering) and a possible shortage in other areas (aerospace, electrical, and industrial engineering).

FUTURE DIRECTIONS

The new challenges of the mid-and late 1980s that will have a significant impact on engineering enrollments include: (1) the decline in college-age youth, which has already resulted in the closing of many elementary and secondary schools; (2) the declining demand for engineering graduates in some areas and the influence of this decline on the new nontraditional students; (3) the increasing restrictions on foreign student visas; and (4) the impact of higher admissions standards in undergraduate and graduate engineering programs. Taken together, these factors may constrain the supply of new engineering graduates at a time when the increasing importance of technology in domestic and international arenas, coupled with the retirement of large numbers of engineers who were educated after World War II, will exert upward pressures on demand.

Two-year and four-year engineering technology programs and industrial technology programs constitute alternative sources of engineering-related manpower, which may be available not only in community colleges, technical institutes, and four-year nonprofit institutes but also among proprietary institutions as well. There is also reason to believe that current national concerns about quality education, especially in mathematics, science, and computer technology, combined with the concern of most states and many communities about "high technology," may create a new demand for and interest in engineering and engineering-related education.

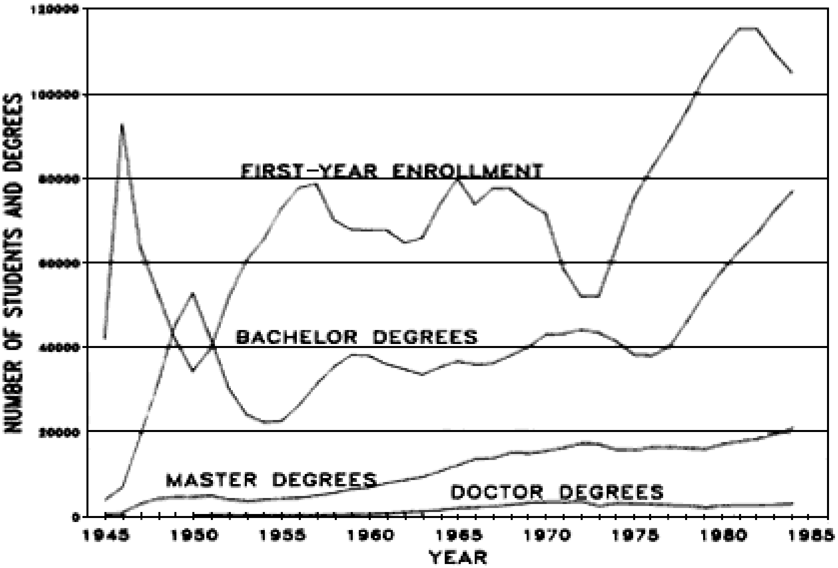


Figure B-1
Trends in engineering first-year enrollments and bachelor's, master's, and doctoral degrees awarded in U.S. colleges and universities from 1945 to 1984. Sources: See Table B-1.

TABLE B-1 Trends in First-Year Engineering Enrollments and Degrees Awarded, 1945–1984

	First-Year Enrollment		Bachelor's Degrees		Master's Degrees		Doctoral Degrees	
Year	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]
1945	42,000	81	4,000	9	500	3	82	3
1946	93,000	179	7,000	16	1,000	6	133	5
1947	64,000	123	19,000	44	3,100	18	252	10
1948	53,000	102	31,000	71	4,300	25	360	14
1949	41,863	81	45,200	104	4,798	28	417	16
1950	34,299	66	52,732	121	4,794	28	494	19
1951	39,571	76	41,893	96	5,031	29	586	23
1952	51,631	99	30,286	70	4,014	23	586	23
1953	60,478	116	24,164	56	3,635	21	592	23
1954	65,505	126	22,236	51	4,078	24	590	23
1955	72,825	140	22,589	52	4,379	26	599	23
1956	77,738	150	26,306	61	4,589	27	610	24
1957	78,757	152	31,211	72	5,093	30	596	23
1958	70,029	135	35,332	81	5,669	33	647	25
1959	67,704	130	38,134	88	6,615	39	714	28
1960	67,556	130	37,808	87	6,989	41	786	30
1961	67,575	130	35,860	83	7,977	47	943	36
1962	64,707	125	34,735	80	8,748	51	1,207	47
1963	65,740	127	33,458	77	9,460	55	1,378	53
1964	73,682	142	35,226	81	10,827	63	1,693	65
1965	79,872	154	36,691	84	12,246	71	2,124	82
1966	73,814	142	35,815	82	13,677	80	2,303	89
1967	77,551	149	36,186	83	13,887	81	2,614	101
1968	77,484	149	38,002	88	15,152	88	2,933	113
1969	74,113	143	39,972	92	14,980	87	3,387	131
1970	71,661	138	42,966	99	15,548	91	3,620	140
1971	58,566	113	43,167	99	16,383	96	3,640	141
1972	52,100	100	44,190	102	17,356	101	3,774	146
1973	51,925	100	43,429	100	17,152	100	2,587	100
1974	63,444	122	41,407	95	15,885	93	3,362	130
1975	75,343	145	38,210	88	15,773	92	3,138	121
1976	82,250	158	37,970	87	16,506	96	2,977	115
1977	88,780	171	40,095	92	16,551	96	2,814	109
1978	95,805	185	46,091	106	16,182	94	2,573	99
1979	103,724	200	52,598	121	16,036	93	2,185	84
1980	110,149	212	58,117	134	17,220	100	2,753	106
1981	115,280	222	62,935	145	17,914	104	2,841	110
1982	115,300	222	66,990	154	18,543	108	2,887	112
1983	109,638	211	72,471	167	19,673	115	3,023	84
1984	105,099	202	76,931	177	20,992	122	3,234	125

[a] All enrollment and degree data are indexed to 1973 as the base (i.e., 1973 = 100). Sources: 1945–1966 data: U.S. Office of Education; 1967–1984 data: Engineering Manpower Commission.

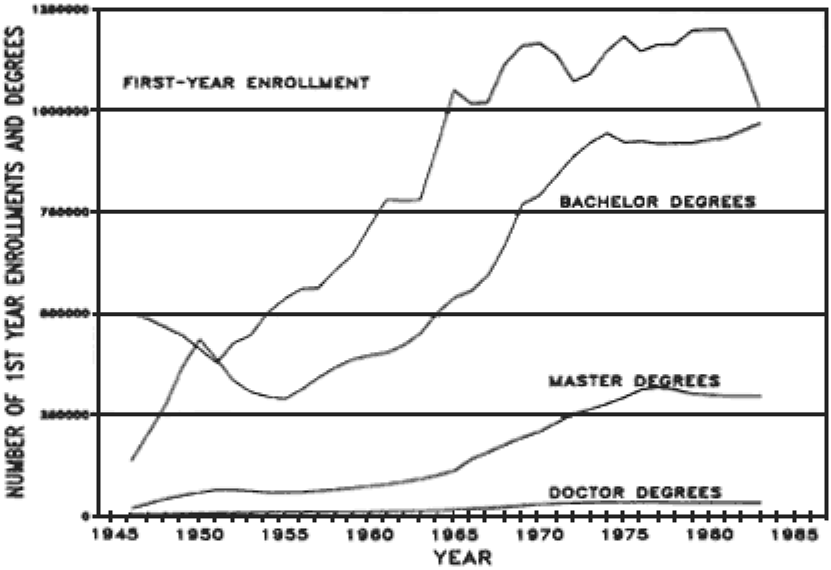


Figure B-2
Trends in total first-year enrollments in four-year U.S. institutions and total bachelor's, master's, and doctoral degrees awarded from 1946 to 1983.
Sources: See Table B-2.

TABLE B-2 Trends in First-Year Enrollments in U.S. Colleges and Universities and Degrees Awarded, 1946–1983

	First-Year Enrollments				Degrees Awarded					
	All Institutions		Four-Year Institutions		Bachelor's Degrees		Master's Degrees		Doctoral Degrees	
Year	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]
1946[b]	650,000[c]	29	500,000[c]	46	136,174	15	19,209	7	1,966	6
1947	592,846	26	484,655	44	204,242[c]	22	30,892[c]	12	2,977[c]	9
1948	575,351[c]	26	464,189[c]	43	272,311	30	42,449	16	3,989	11
1949	557,856	25	443,723	41	366,698	40	50,763	19	5,050	15
1950	516,836	23	410,325	38	433,734	47	58,219	22	6,420	18
1951	472,025	21	376,493	35	384,352	42	65,132	25	7,338	21
1952	536,879	24	425,937	39	331,924	36	63,587	24	7,683	22
1953	571,533	25	445,665	41	304,857	33	61,023	23	8,309	24
1954	631,122	28	500,735	46	292,880	32	56,823	22	8,996	26
1955	675,060	30	534,800	49	287,401	31	58,204	22	8,840	25
1956	723,178	32	559,801	51	311,298	34	59,294	23	8,903	26
1957	729,725	32	561,653	51	340,347	37	61,995	24	8,756	25
1958	781,075	35	605,669	56	365,748	40	65,614	25	8,942	26
1959	826,969	37	644,284	59	385,151	42	69,584	26	9,360	27
1960	929,823	41	714,440	65	394,889	43	74,497	28	9,829	28
1961	1,026,087	46	780,510	72	401,784	44	78,269	30	10,575	30
1962	1,030,620	46	776,852	71	420,485	46	84,889	32	11,622	22
1963	1,055,146	47	782,029	72	450,592	49	91,418	35	12,822	37
1964	1,234,806	55	911,340	84	502,104	54	101,122	38	14,490	42
1965	1,452,926	65	1,050,569	96	538,930	58	112,195	43	16,467	47
1966	1,565,564	70	1,018,592	93	555,613	60	140,772	53	18,239	52
1967	1,652,317	73	1,022,113	94	594,862	64	157,892	60	20,621	59
1968	1,907,938	85	1,115,900	102	671,591	73	177,150	67	23,091	66
1969	1,986,844	88	1,160,192	106	769,683	83	194,414	74	26,189	75
1970	2,080,244	93	1,166,391	107	792,316	86	208,291	79	29,866	86

	First-Year Enrollments				Degrees Awarded					
	All Institutions		Four-Year Institutions		Bachelor's Degrees		Master's Degrees		Doctoral Degrees	
Year	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]	Number	% / 1973[a]
1971	2,135,947	95	1,138,418	104	839,730	91	230,509	88	32,107	92
1972	2,171,268	97	1,073,427	98	887,273	96	251,633	96	33,363	96
1973	2,248,100	100	1,091,143	100	922,362	100	263,371	100	34,777	100
1974	2,392,869	106	1,147,158	105	945,776	103	277,033	105	33,816	97
1975	2,543,552	113	1,182,945	108	922,933	100	292,450	111	34,083	98
1976	2,377,242	106	1,146,781	105	925,746	100	311,771	118	34,064	98
1977	2,431,600	108	1,163,004	107	919,549	100	317,164	120	33,232	96
1978	2,422,398	108	1,163,685	107	921,204	100	311,620	118	32,131	92
1979	2,538,119	113	1,197,571	110	921,390	100	301,079	113	32,730	94
1980	2,625,138	117	1,209,451	111	929,417	101	298,081	113	32,618	94
1981	2,636,231	117	1,201,264	113	935,140	101	295,739	112	32,958	94
1982	2,505,000	111	1,118,000	102	952,998	103	295,546	112	32,701	94
1983	2,444,000	109	1,005,000	92	970,000[c]	105	295,000[c]	112	32,700[c]	94

[a] All enrollment and degree data are indexed to 1973 as the base (i.e., 1973 = 100).

[b] Data prior to 1965 are degree-credit enrollments only. For 1965 and later, the figures indicate total degree-credit and non-degree-credit enrollments.

[c] Estimated.

SOURCES: Data on first-year enrollments for 1947–1969: *Fact Book on Higher Education* (First issue, 1970). Data on degrees awarded, 1947–1969: *Fact Book on Higher Education* (Fourth issue, 1970). Data on first-year enroll merits for 1970–1979:*1981 – 1982 Fact Book*. Data on degrees awarded, 1970–1979: *Digest of Education Statistics* (1982).

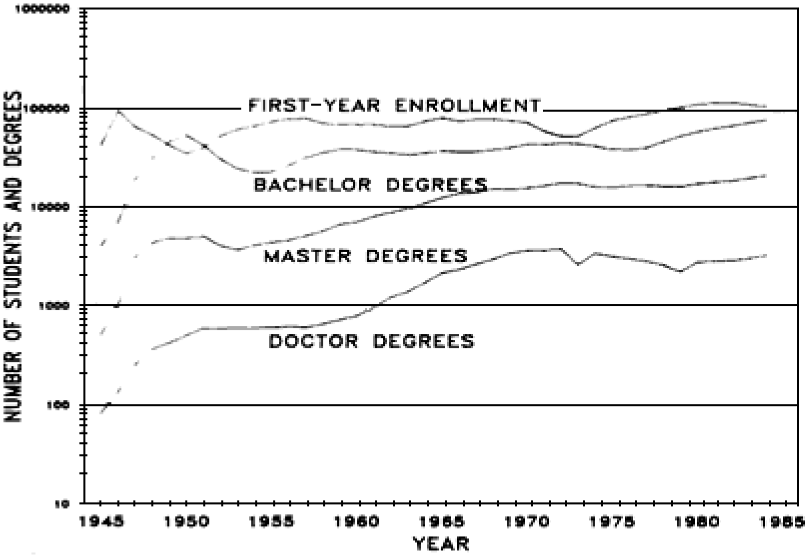


Figure B-3
Trends in engineering first-year enrollments and bachelor's, master's, and doctoral degrees awarded in U.S. colleges and universities from 1945 to 1984 (semilog scale). Sources: See Table B-1.

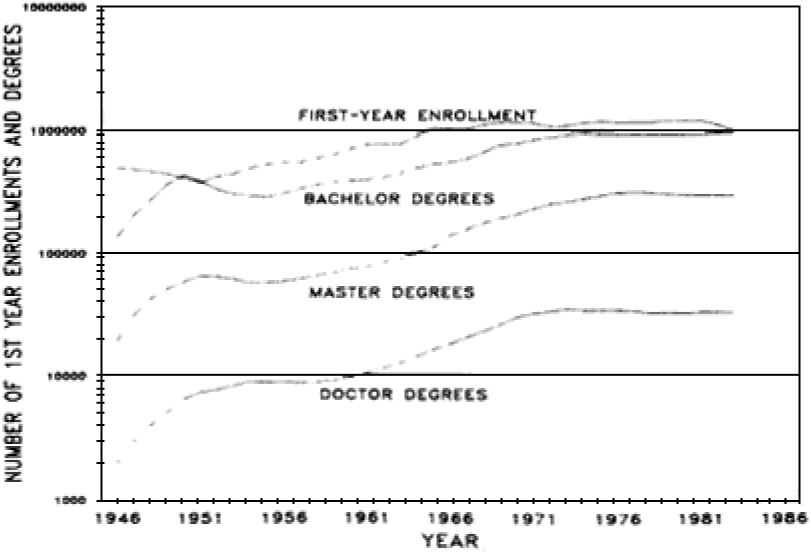


Figure B-4
Trends in total first-year enrollment in four-year U.S. institutions and total bachelor's, master's, and doctoral degrees awarded from 1946 to 1983 (semilog scale). Sources: See Table B-2.

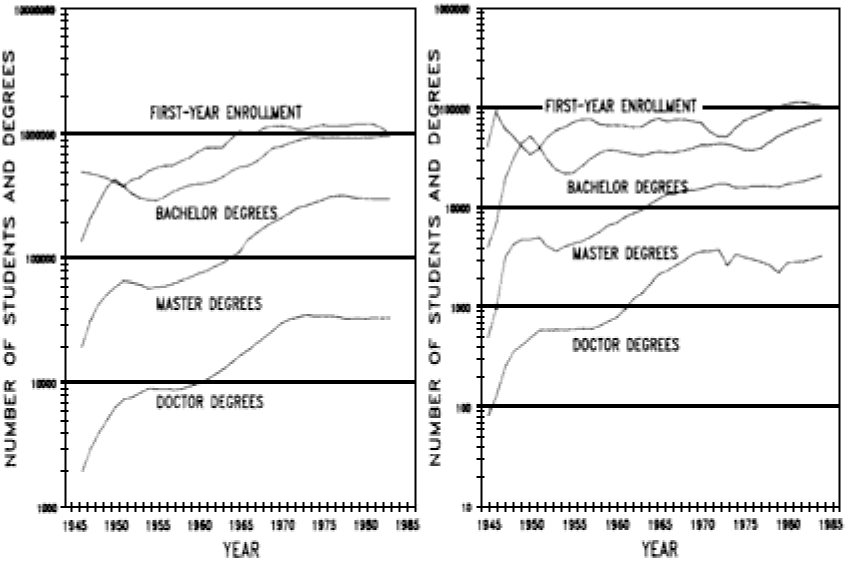


Figure B-5
Trends in engineering first-year enrollments and total first-year enrollment in four-year U.S. institutions, and total bachelor's, master's, and doctoral degrees awarded in U.S. colleges and universities from 1945 to 1984.

TABLE B-3 Trends in First-Year Engineering Enrollments and Degrees, by Sex and Ethnic Minority, 1973–1984

	First-Year Enrollments																	
	Black		Hispanic		American Indian		Asian Pacific		Foreign Nationals		Women		Total		Under-represented Minorities		Total Male	
Year	No.	%/1973[a]	No.	%/1973[a]	No.	%/1973[a]	No.	%1973[a]	No.	%/1973[a]	No.	%/1973[a]	No.	%/1973[a]	No.	%/1973[a]	No.	%/1973[a]
1973	2,130	100	790	100	67	100	884	100	750[b]	100	2,417	100	51,920	100	2,987	100	49,503	100
1974	2,848	134	1,068	135	102	152	1,130	128	1,000[b]	133	4,266	176	63,440	122	4,018	135	59,174	120
1975	3,840	180	1,384	175	120	179	1,155	131	2,500[b]	333	6,730	278	75,343	145	5,344	179	68,613	139
1976	4,372	205	1,766	224	171	255	1,560	176	3,000[b]	400	8,545	354	82,250	158	6,309	211	73,705	149
1977	4,728	222	2,121	268	244	364	1,847	209	4,000[b]	533	9,921	410	88,780	171	7,093	237	78,859	159
1978	5,493	258	2,662	337	225	336	2,169	245	4,500[b]	600	11,789	488	95,805	185	8,380	281	84,016	170
1979	6,339	298	3,136	397	317	473	3,133	354	4,984	665	14,031	581	103,724	200	9,792	328	89,693	181
1980	6,661	313	3,373	427	365	545	2,889	327	5,095	679	16,004	662	110,149	212	10,399	348	94,145	190
1981	7,015	329	3,689	467	412	615	4,035	456	4,974	663	18,238	755	115,280	222	11,116	372	97,042	196
1982	6,715	315	3,635	460	371	554	4,098	464	4,925	657	19,155	793	115,303	222	10,721	359	96,148	194
1983	6,342	298	4,760	603	376	561	4,983	564	5,234	698	18,689	773	109,638	211	11,473	384	90,949	184
1984	6,265	294	4,844	613	410	612	5,654	640	4,830	644	17,356	718	104,629	202	11,249	377	87,553	177

	Bachelor's Degrees Awarded																	
	Black		Hispanic		American Indian		Asian Pacific		Foreign Nationals		Women		Total		Under-represented Minorities		Total Male	
Year	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	% 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]
1973	657	100	566	100	46	100	684	100	2,136	100	624	100	43,429	100	1,269	100	42,805	100
1974	756	115	640	113	32	70	957	140	2,436	114	744	119	41,407	95	1,428	113	40,663	95
1975	734	112	685	121	44	96	883	129	2,466	115	878	141	38,210	88	1,463	115	37,332	87
1976	777	118	680	120	41	89	1,074	157	2,799	131	1,317	211	37,970	87	1,498	118	36,653	86
1977	844	128	658	116	36	78	1,146	168	2,996	140	2,022	324	40,095	92	1,538	121	38,073	89
1978	894	136	743	131	37	80	1,195	175	3,084	144	3,479	558	46,091	106	1,674	132	42,612	100
1979	1,076	164	808	143	59	128	1,532	224	3,788	177	4,880	782	52,598	121	1,943	153	47,718	111
1980	1,320	201	1,003	177	60	130	1,922	281	4,895	229	6,438	1,032	58,742	135	2,383	188	52,304	122
1981	1,445	220	1,513	267	90	196	2,267	331	5,622	263	7,699	1,234	62,935	145	3,048	240	55,236	129
1982	1,644	250	1,608	284	91	198	2,577	377	5,410	253	8,140	1,304	66,990	154	3,343	263	58,850	137
1983	1,900	289	1,894	335	97	211	3,114	455	5,620	263	9,566	1,533	72,471	167	3,891	307	62,905	147
1984	2,022	308	2,038	360	112	243	3,609	528	5,833	273	10,761	1,724	76,931	177	4,172	329	66,170	155

Master's Degrees Awarded

	Black		Hispanic		American Indian		Asian Pacific		Foreign Nationals		Women		Total		Under-represented Minorities		Total Male	
Year	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	% 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]
1973	104	100	132	100	15	100	261	100	2,551	100	226	100	17,152	100	251	100	16,926	100
1974	158	152	187	142	4	27	425	163	3,099	121	393	174	15,885	93	349	139	15,492	92
1975	141	136	176	133	3	20	482	185	3,250	127	380	168	15,773	92	320	127	15,393	91
1976	154	148	183	139	14	93	782	300	3,691	145	557	246	16,506	96	351	140	15,949	94
1977	147	141	210	159	7	47	708	271	3,825	150	697	308	16,551	96	364	145	15,854	94
1978	202	194	234	177	4	27	797	305	3,720	146	840	372	16,182	94	440	175	15,342	91
1979	159	153	205	155	9	60	675	259	3,944	155	934	413	15,624	91	373	149	14,690	87
1980	167	161	247	187	4	27	827	317	4,512	177	1,142	505	17,234	100	418	167	16,092	95
1981	182	175	276	209	7	47	968	371	4,677	183	1,362	603	17,914	104	465	185	16,552	98
1982	184	177	215	163	15	100	850	326	5,284	207	1,539	681	18,534	108	414	165	16,995	100
1983	268	258	311	236	16	107	1,290	494	4,915	193	1,782	788	19,673	115	595	237	17,891	106
1984	253	243	358	271	25	167	1,341	514	5,648	221	2,136	945	20,992	122	636	253	18,856	111

Doctoral Degrees Awarded

	Black		Hispanic		American Indian		Asian Pacific		Foreign Nationals		Women		Total		Under-represented Minorities		Total Male	
Year	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	% 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]	No.	%/ 1973[a]
1973	13	100	12	100	1	100	55	100	708	100	48	100	3,587	100	26	100	3,539	100
1974	12	92	19	158	0	0	106	193	1,014	143	36	75	3,362	94	31	119	3,326	94
1975	17	131	28	233	2	200	141	256	891	126	53	110	3,039	85	47	181	2,986	84
1976	10	77	15	125	0	0	168	305	1,060	150	56	117	2,977	83	25	96	2,921	83
1977	16	123	22	183	1	100	158	287	995	141	67	140	2,814	78	39	150	2,747	78
1978	15	115	25	208	3	300	175	318	874	123	51	106	2,573	72	43	165	2,522	71
1979	19	146	22	183	0	0	177	322	929	131	61	127	2,815.	78	41	158	2,754	78
1980	19	146	25	208	1	100	154	280	982	139	88	183	2,751	77	45	173	2,663	75
1981	16	123	20	167	3	300	148	269	1,054	149	90	188	2,841	79	39	150	2,751	78
1982	11	85	26	217	2	200	124	225	1,167	165	126	263	2,887	80	39	150	2,761	78
1983	19	146	41	342	0	0	174	316	1,179	167	142	296	3,023	84	60	231	2,881	81
1984	24	185	25	208	0	0	267	485	1,253	177	153	319	3,234	90	49	188	3,081	87

[a] All enrollment and degree data are indexed to 1973 as the base (i.e., 1973 = 100).

[b] Estimated.

SOURCE: Engineering Manpower Commission.

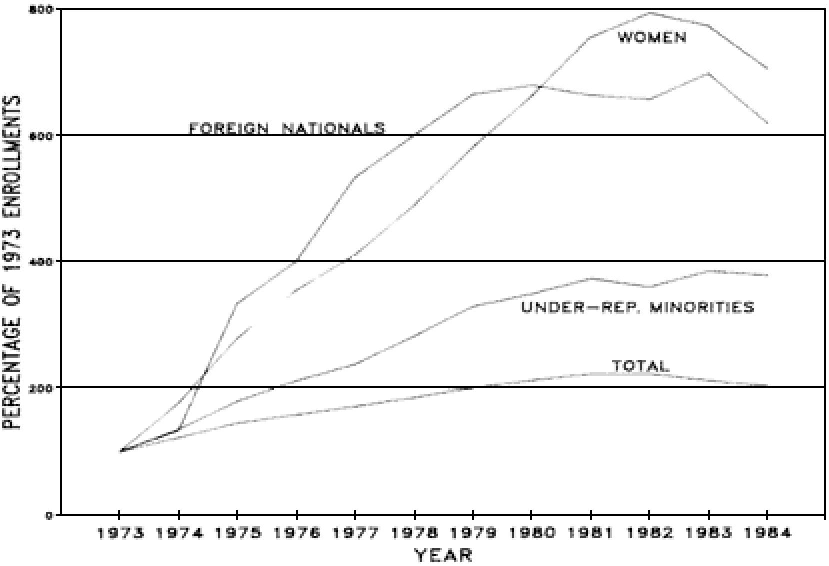


Figure B-6
First-year engineering enrollments for 1973 to 1984, shown as a percentage of 1973 enrollments (1973 = 100). Source: Engineering Manpower Commission.

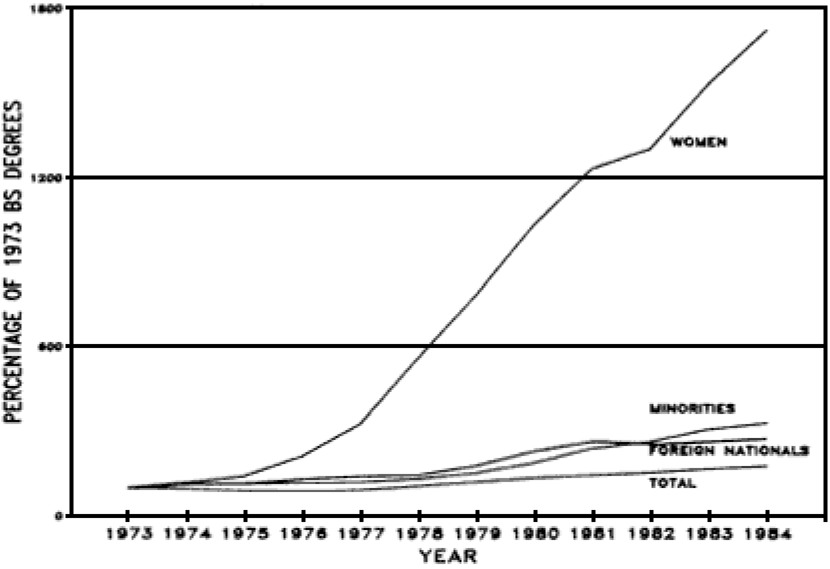


Figure B-7
Engineering bachelor's degrees awarded from 1973 to 1984, shown as a percentage of 1973 awards (1973 = 100). Source: Engineering Manpower Commission.

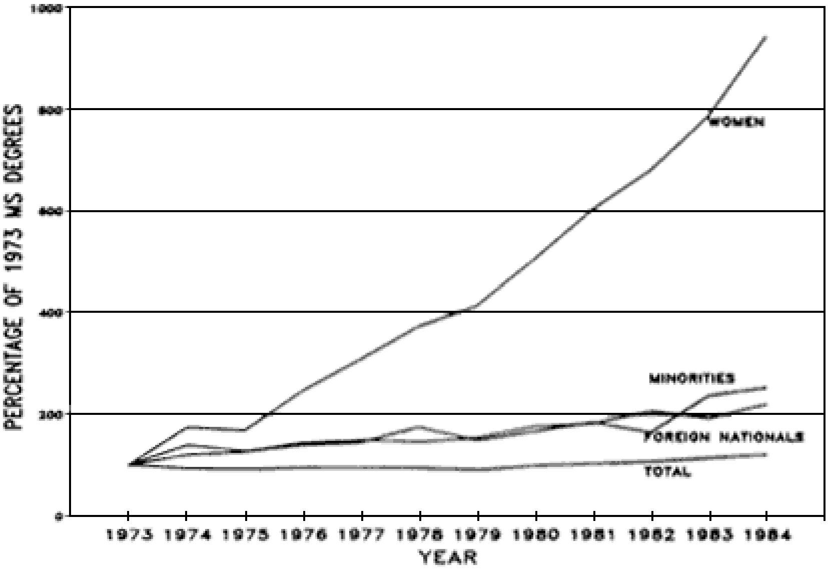


Figure B-8
Engineering master's degrees awarded from 1973 to 1984, shown as a percentage of 1973 awards (1973 = 100). Source: Engineering Manpower Commission.

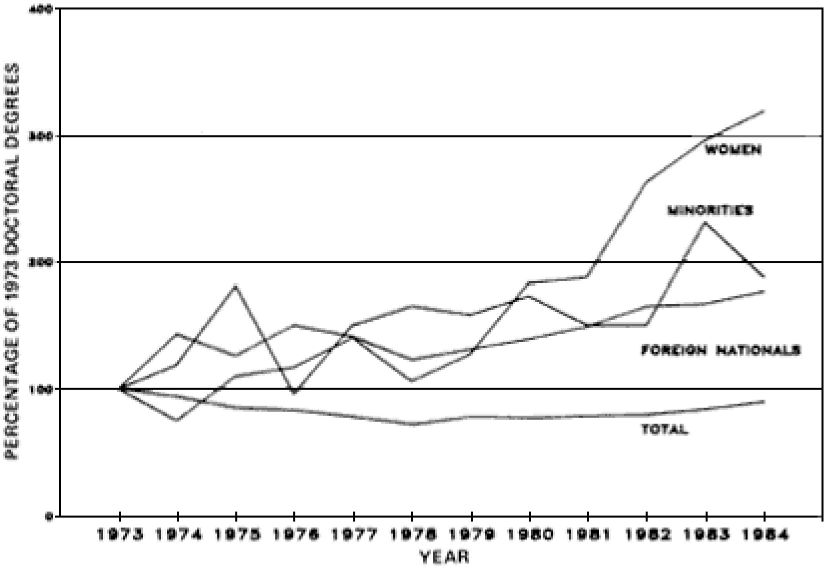


Figure B-9
Engineering doctoral degrees awarded from 1973 to 1984, shown as a percentage of 1973 awards (1973 = 100). Source: Engineering Manpower Commission.

TABLE B-4 Trends in Engineering Technology and Industrial Technology First-Year Enrollments, Associate Degree Pre-Engineering and Bachelor's Degree Programs for Women and Ethnic Minorities, 1972–1984

First-Year Fall Enrollments for Associate Degree and Pre-Engineering[a] Programs

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
		% /		% /		% /		% /		% /		% /
Year	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]
1972	2,052	80	—	—	—	—	—	—	1,536	66	69,179	102
1973	2,569	100	1,321	100	213	100	199	100	2,315	100	68,024	100
1974	2,732	106	1,478	112	352	165	303	152	2,745	119	61,372	90
1975	3,325[c]	129	1,884[c]	143	464[c]	218	494[c]	248	3,282[c]	142	61,979[c]	91
1976	3,917	152	2,290	173	576	270	685	344	3,819	165	55,792	82
1977	4,347	169	2,908	220	408	192	736	370	4,877	211	56,171	83
1978	3,892	151	2,004	152	342	161	791	397	4,333	187	44,934	66
1979	4,101	160	1,214	92	335	157	718	361	5,621	243	47,517	70
1980	5,888	229	2,586	196	412	193	981	493	8,754	378	67,971	100
1981	4,519	176	1,668	126	420	197	1,015	510	7,838	339	55,202	81
1982	4,567	178	2,015	153	245	115	1,048	527	6,472	280	51,513	76
1983	3,512	137	1,475	112	311	146	807	406	4,296	186	36,866	54
1984	2,611	102	1,206	91	257	121	641	322	3,640	157	29,211	43

First-Year Fall Enrollments for Bachelor of Engineering Technology Programs

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
Year	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]
1972	260	88	—	—	—	—	—	—	75	54	4,345	89
1973	295	100	79	100	8	100	22	100	138	100	4,869	100
1974	260	88	65	82	9	113	32	145	189	137	4,506	93
1975	453[c]	154	152[c]	192	29[c]	393	58[c]	264	308	223	6,393	131
976	646	219	238	301	49	613	84	382	426	6309	7,134	147
1977	968	328	262	332	42	525	82	373	587	425	9,506	195
1978	644	218	182	230	45	563	97	441	681	493	8,420	173
1979	660	224	184	233	32	400	151	686	800	580	8,680	178
1980	1,071	363	151	191	48	600	127	577	1,085	786	10,998	226
1981	1,209	410	213	270	42	525	192	873	1,360	986	10,691	220
1982[d]	818	277	216	273	32	400	197	895	762	552	7,826	161
1983	2,544	862	730	924	105	1,313	420	1,909	1,284	930	16,166	332
1984	2,588	877	918	1,162	65	813	432	1,964	2,211	1,602	17,595	361

Engineering Technology Associate Degrees Awarded During the Calendar Year

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
		% /		% /		% /		% /		% /		% /
Year	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]
1973	583	100	486	100	76	100	74	100	436	100	18,316	100
1974	536	92	323	66	47	62	137	185	581	133	17,537	96
1975	598	103	345	71	71	93	146	197	502	115	16,978	93
1976	793	136	536	110	28	37	183	247	780	179	16,685	91
1977	594	102	350	72	25	33	144	195	825	189	15,123	83
1978	739	127	371	76	85	112	194	262	947	217	16,099	88
1979	538	92	445	92	28	37	197	266	1,060	243	14,622	80
1980	848	145	600	123	20	26	219	296	1,219	280	15,817	86
1981	924	158	528	109	37	49	256	346	1,637	375	17,975	98
1982	663	114	283	58	46	61	286	386	1,656	380	17,198	94
1983	931	160	426	88	58	76	361	488	1,954	448	19,329	106
1984	877	150	447	92	65	86	343	464	1,841	422	18,432	101

Engineering Technology Bachelor's Degrees Awarded During The Calendar Year

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
		% /		% /		% /		% /		% /		% /
Year	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]
1973	151	100	41	100	3	100	52	100	42	100	4,402	100
1974	226	150	95	232	10	333	89	171	29	69	4,830	110
1975	228	151	137	334	8	267	92	177	60	143	5,867	133
1976	254	168	112	273	11	367	74	142	24	57	5,721	130
1977	256	170	122	298	9	300	93	179	147	350	6,337	144
1978	295	195	125	305	12	400	114	219	191	455	7,164	163
1979	310	205	144	351	11	367	211	406	246	586	6,609	150
1980	382	253	150	366	8	267	145	279	299	712	7,567	172
1981	296	196	171	417	14	467	258	496	387	921	8,469	192
1982	292	193	220	537	18	600	199	383	333	793	8,325	189
1983	351	232	235	573	10	333	259	498	480	1,143	9,222	209
1984	582	385	314	766	14	467	372	715	744	771	10,182	231

Industrial Technology[d] Associate Degrees Awarded During the Calendar Year

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
Year	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]	Number	% / 1973[b]
1973	165	100	76	100	9	100	18	100	278	100	6,481	100
1974	227	138	175	230	91	1,011	29	161	246	88	7,389	114
1975	215	130	148	195	79	878	30	167	316	114	5,816	90
1976	339	205	261	343	19	211	113	628	433	156	6,362	98
1977	131	79	180	237	6	67	31	172	347	125	5,346	82
1978	510	309	210	276	23	256	91	506	605	218	6,660	103
1979	275	167	254	334	39	433	49	272	516	186	5,306	82
1980	318	193	217	286	11	122	58	322	633	228	5,937	92
1981	362	219	283	372	78	867	108	600	933	336	7,340	113
1982	336	204	160	211	30	333	101	561	710	255	6,514	101

Industrial Technology[d] Bachelor's Degrees Awarded During the Calendar Year

	Black		Hispanic		American Indian		Asian Pacific		Women		Total	
		% /		% /		% /		% /		% /		% /
Year	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]	Number	1973[b]
1973	85	100	6	100	6	100	2	100	28	100	2,076	100
1974	66	78	22	367	1	17	16	800	11	39	1,631	79
1975	80	94	36	600	2	33	14	700	25	89	2,042	98
1976	111	131	17	283	3	50	5	250	24	86	1,358	65
1977	87	102	26	433	6	100	36	1,800	46	164	1,345	65
1978	114	134	19	317	2	33	10	500	120	429	2,202	106
1979	180	212	28	467	11	183	14	700	120	429	2,105	101
1980	88	104	22	367	10	167	17	850	238	850	2,481	120
1981	244	287	74	1,233	3	50	17	850	331	1,182	3,188	154
1982	85	100	47	783	33	550	24	1,200	259	925	3,110	150

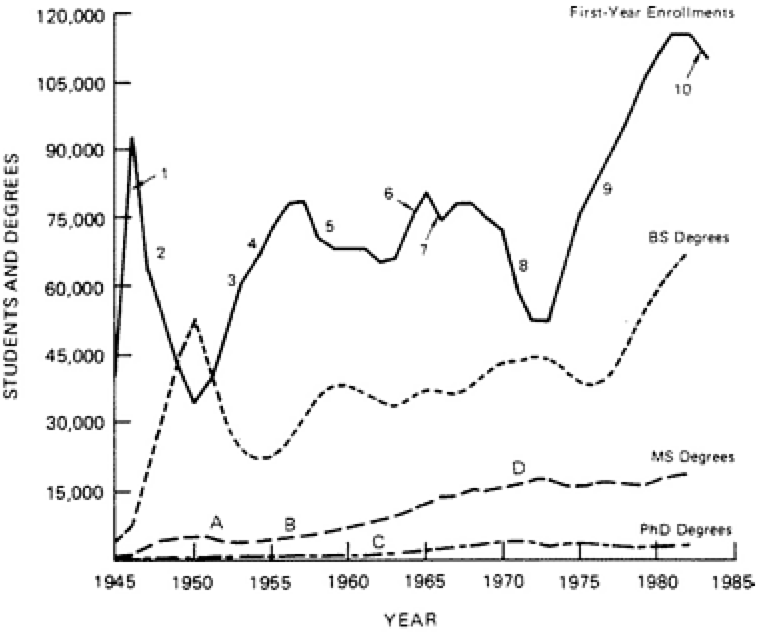
[a] Beginning in 1983, some pre-engineering programs were included with the Bachelor of Engineering Technology programs.

[b] All enrollment data are indexed to 1973 as the base (i.e., 1973 = 100).

[c] Estimated.

[d] The Engineering Manpower Commission eliminated monitoring of industrial technology programs beginning in 1982.

SOURCE: Engineering Manpower Commission.



1. Returning World War II veterans
2. Diminishing veteran pool and expected surplus of engineers
3. Korean War and increasing R&D expenditures
4. Returning Korean War veterans
5. Aerospace program cutbacks and economic recession
6. Vietnam War and greater space expenditures
7. Increased student interest in social-program careers
8. Adverse student attitudes toward engineering, decreased space and defense expenditures, and lowered college attendance
9. Improved engineering job market, positive student attitudes toward engineering, and entry of nontraditional students (women, minorities, and foreign nationals)
10. Diminishing 18-year-old pool

A *Manual on Graduate Study in Engineering* issued, based on 1945 Committee Report chaired by L. E. Grinter

B ASEE Evaluation Report recommends greater stress on mathematics and science and the engineering sciences.

C ASEE Committee on the Development of Engineering Faculties recommends the doctorate for future engineering faculty.

D ASEE *Goals of Engineering Education* recommends the master's degree for the majority of those who complete their undergraduate degree in the coming decade.

Figure B-10
Historical factors influencing changes in engineering enrollments and degrees awarded from 1945 to 1984.

Appendix C

Flow Diagrams

GLOSSARY OF TERMS USED IN COMPREHENSIVE FLOW DIAGRAM

The following definitions are listed in the approximate order of their appearance in progressive flow through the comprehensive flow diagram of the engineering community that was presented in Chapter 3. The definitions are divided by stages.

ENTRY POOL—	that body of persons qualified and positioned to be admitted to the U.S. higher-education system.
U.S. Secondary Students—	all students enrolled in degree-granting programs in U.S. public and private secondary schools.
Dropouts—	those U.S. high school students who did not pursue a program to completion.
Noncollege —	those graduates of U.S. secondary schools who are not admitted within three years to a degree-granting program of higher education.
Foreign Students—	Noncitizens who have been admitted to U.S. higher-education systems based on education pursued outside the United States.
Reentering Adults—	past graduates of the U.S. secondary school system admitted to higher education after a three-year or longer lapse since graduation.
EDUCATIONAL PREPARATION—	persons enrolled full time in U.S. higher-education institutions at all degree levels.

Engineering Students—	students enrolled in any engineering programs leading to a B.S. or M.S. degree.
Science/ Math Students—	persons enrolled in any program leading to a B.S. or M.S. degree in chemistry, physics, biology, mathematics, or computer science and related disciplines.
Technology Students—	students enrolled in four-year technology programs leading to a B.S. or M.S. degree.
Nontechnical Students—	all students enrolled in four-year degree-granting institutions who are not included as engineering/science/ math or technology students; all degree levels from bachelor's through Ph.D. are included in this group.
Collegiate Below B.S.: Technical—	persons enrolled full time in programs granting less than a bachelor's degree in areas associated with engineering and science (for example, associate degrees or certificates in areas such as electrical engineering technology, computer programming, or instrumentation).
Collegiate Below B.S.: Nontechnical—	All persons enrolled in programs granting degrees below the bachelor's level who are not counted in the "Collegiate Below B.S.: Technical" category.
Dropouts—	those enrolled students in any higher-education program who leave the program before graduation without a commitment to reenter or transfer to a different program.
Engineering Ph.D. Students—	students admitted to an accredited Ph.D. program who are actively working toward the degree.
Science/ Math/Technology Ph.D. Students—	students actively working toward the Ph.D. degree in chemistry, physics, biology, computer science, mathematics, technology, or related fields of study.
Ph.D. Graduates—	students who have completed all requirements and been granted a Ph.D. degree.
Ph.D. Nongraduates—	students leaving a Ph.D. program without completing all the requirements and being granted a degree.
Foreign Ph.D. Students—	noncitizens admitted to the Ph.D. program in U.S. schools based on credentials obtained in some other country.
EMPLOYED IN ENGINEERING COMMUNITY—	persons employed in any pool in the engineering community.
Engineer Pool—	that body of persons who meet the definition of engineer developed by the Panel on Infrastructure Diagramming and Modeling (see Chapter 1).

Immigrant Engineers—	persons entering the engineer pool who qualify under the definition of engineer (see Chapter 1) and whose educational preparation was in a foreign country.
Engineering Faculty Pool—	persons holding budgeted full-time faculty positions in degree-granting engineering departments, regardless of degree level, rank, or tenure status.
Staff Support—	that body of people, regardless of educational preparation, who occupy positions in direct managerial, financial, or other staff support areas to assist activities of the engineer, faculty, or technologist/technician pools. These people may or may not be qualified for these pools, but they are not currently functioning in any of them. Any person whose position is clearly within the engineering community by the nature of the services rendered should be classified as staff support. Such services include but are not limited to technical management, operations research, financial analysis, data processing, technical sales, procurement, and safety.
Technologist/Technician Pool—	that body of persons who meet the definitions for technologist or technician formulated by the Panel on Infrastructure Diagramming and Modeling (see Chapter 1).
Immigrant Technicians—	persons entering the technologist/ technician pool whose educational preparation was in a foreign country.
General Work Force—	persons entering the technologist/ technician pool based on performance in the general work force or after internal training. These people may or may not have had higher educational preparation in the past.
OUT OF ENGINEERING COMMUNITY—	those persons who have been either actual or potential members of the engineering community but are not currently employed in it.
Technical Reserve Pool—	persons who by educational preparation, experience, or both are qualified (with reasonable retraining) to function in the engineering community but are presently outside it. Included would be such groups as unemployed engineers, retired persons, and technical graduates who never entered or have left engineering-related work. A "test" for the diverse group that makes up the technical reserve is this: Could this person with sufficient motivation (e.g., financial, national emergency) be reasonably expected to enter or reenter the engineering community?
Exit: Return to Home Country—	foreign graduates at any degree level who leave the United States for emigration or other reasons after graduation or a reasonable period for practical experience.
Exit: Death, Disability, Emigration—	persons who were at one

	time employed in the engineering community or were in the technical reserve and who are permanently lost to the system.
Exit: Other Work—	persons who were potential entrants to the engineering community by virtue of nontechnical or collegiate-below-B. S. degrees but who chose other fields of work.

LABELING SYSTEM FOR FLOW DIAGRAMS

The labeling system for the detailed flow diagrams in Figure 3, Chapter 3, and in Diagrams A-1 through F-1 in this appendix is as follows:

Label = Letter + 4 Digits

The letter indicates one of six major categories of stocks and flows.
A = Entry Pool
B = Educational Preparation—B.S./M.S.
C = Educational Preparation—Ph.D.
D = Employed in the Engineering Community
E = Exit from the Engineering Community
F = Temporary Exit—Technical Reserve

The first of the four digits represents a *stock* in one of the categories. (For example, B-2000 represents the pool of science and math students in the undergraduate educational system.) The second digit represents a *flow* into or out of one of the stocks and is followed by two zeros. For example, B-2200 represents the aggregated transfer of students into science and math from other curricula. B-2600 represents the flow of M.S. graduates out of science and math.

A labeling convention was adopted whereby an aggregated flow from one stock to another bears the label of the originating stock. For example, in Diagram D-1, Flows of the Engineering Pool, the flow *out* of the engineer pool (D-1000) into the staff support pool (D-3000) bears the label D-1700, but the counterflow into the engineer pool bears the label D-3100.

The third digit in the label represents a *branch or disaggregation of a major flow* and is followed by a single zero. For example, in the label B-2310, B-____ denotes the educational preparation category; B-2___, the science/math student pool, a major flow; B-23__, in this case, transfers out; and B-2310, transfers to engineering. From the same source, transfers to technology would be labeled B-2330, and so on.

The fourth digit represents a *further disaggregation,* and was necessary only in describing all the options in the entry pool.

DETAILED FLOW DIAGRAMS

Following are the titles of the detailed flow diagrams in this appendix. Each diagram is accompanied by a table that provides numerical data, when available, for the items in the diagram as of 1960, 1970, and 1980.

A-1	Flows of U.S. Secondary Students
A-2	Flows of College-Bound Foreign Students
A-3	Flows of College-Bound Reentering Adults
B-1	Flows Affecting Engineering Students
B-2	Flows Affecting Science/Math Students
B-3	Flows Affecting Technology Students
B-4	Flows Affecting Nontechnical College Students
B-5	Flows Affecting Collegiate Below-B. S. Students: Technical
B-6	Flows Affecting Collegiate Below-B.S. Students: Nontechnical
C-1	Flows Affecting Engineering Ph.D. Students (Full Time)
C-2	Flows Affecting Math/Science/Technology Ph.D. Students (Full Time)
D-1	Flows of the Engineering Pool
D-2	Flows of the Engineering Faculty Pool
D-3	Flows of the Staff Support Pool
D-4	Flows of the Technologist/Technician Pool
E-1	Flows of Foreign Students to Home Country
E-2	Flows of Nontechnical and Below B.S. out of Engineering Community
E-3	Flows out of Engineering Community From Death/Disability/Emigration
F-1	Flows of the Technical Reserve Pool

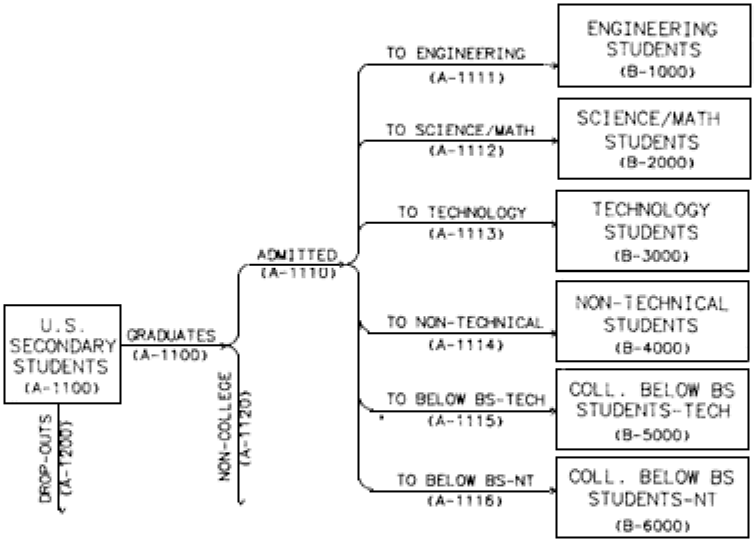


Diagram A-1
Flows of U.S. secondary students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE A-1 Flows of U.S. Secondary Students, 1960, 1970, and 1980 (in thousands)[a]

Label	Description	1960	1970	1980
A-1000	U.S. Secondary Students	9,600.0	14,418.0	15,191.0
A-1100	Secondary School Graduates	1,864.0	2,896.0	3,063.0
A-1110	Admitted to College[b]	759.0	1,426.0	2,108.4
A-1111	To Engineering	67.6	71.7	110.1
A-1112	To Science/Math[c]	92.3	134.9	143.7
A-1113	To Technology	—	4.8	11.0
A-1114	To Nontechnical (4-year plus)	460.1	801.6	944.6
A-1115	To Collegiate Below B.S.—Tech.	20.2	60.0	150.7
A-1116	To Collegiate Below B.S.—NT	118.8	353.5	748.3
A-1120	Noncollege	—	—	—
A-1130	Nondegree College	—	—	—
A-1140	Part-time students	—	—	—
A-1200	High School Dropouts	998.0	929.0	1,099.0

NOTE: Tech. = Technical; NT = Nontechnical.

[a] Includes foreign students.

[b] Does not include part-time students and non-degree-credit students.

[c] Science/Math includes agricultural/natural resources, biology, computer science, math, physical sciences, and general science programs.

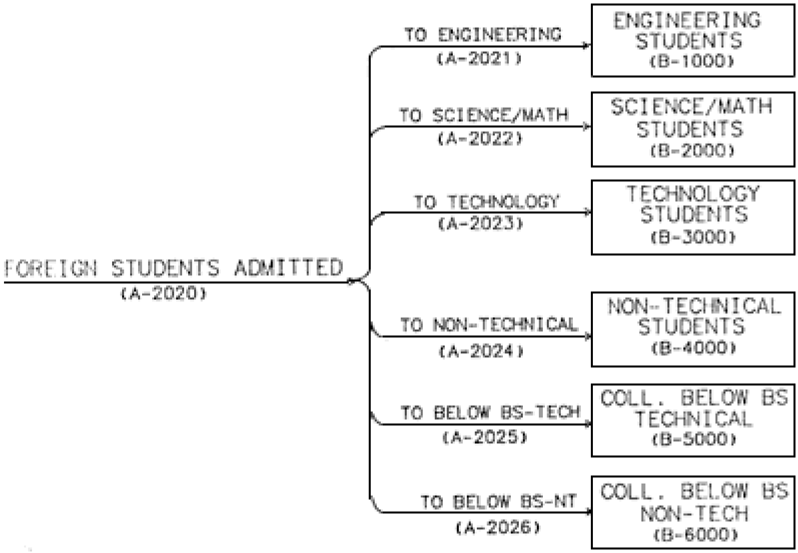


Diagram A-2 Flows of college-bound foreign students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE A-2 Flows of College-Bound Foreign Students, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
A-2020	Foreign Students Admitted	—	—	62.9
A-2021	To Engineering	—	1.6	7.4
A-2022	To Science/Math	—	—	2.1
A-2023	To Technology	—	—	—
A-2024	To Nontechnical College	—	—	37.4
A-2025	To Collegiate Below B.S.—Tech.	—	—	3.1
A-2026	To Collegiate Below B.S.—NT	—	—	12.5

NOTE: Tech. = Technical; NT = Nontechnical.

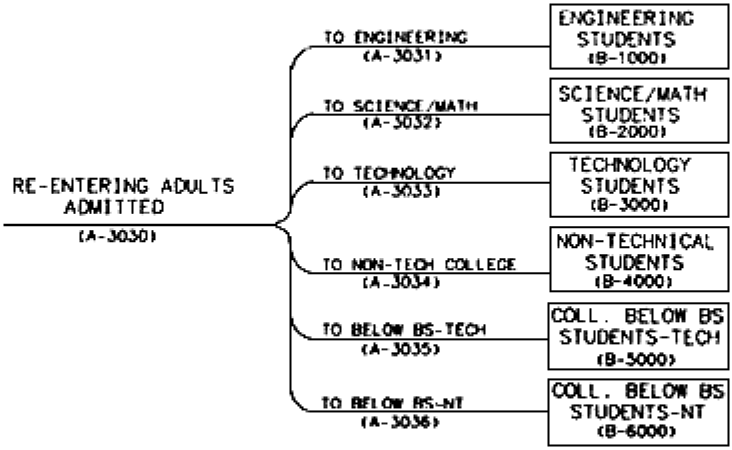


Diagram A-3
Flows of college-bound reentering adults. (See section on "Labeling System for Flow Diagrams" in this appendix.) Note: There are no available data with which to construct a table to accompany Diagram A-3.

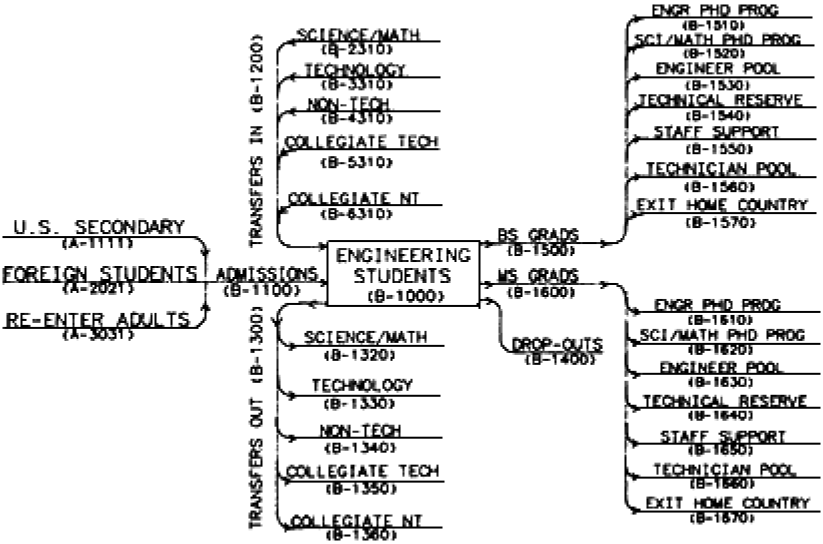


Diagram B-1
Flows affecting engineering students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-1 Flows Affecting Engineering Students, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
B-1000	Engineering Students: B.S.[a]	214.0	231.7	365.1
	M.S.[a]	18.6	23.2	29.9
B-1100	Admissions	67.6	71.7	110.1
A-1111	From U.S. Secondary Schools	67.6	71.7	110.1
A-2021	Foreign Students	—	1.6	7.4
A-3031	Reentering Adults	—	—	—
B-1200	Transfers to Engineering, From:	—	—	—
B-2310	Math/Science	—	—	—
B-3310	Technology	—	—	—
B-4310	Nontechnical	—	—	—
B-5310	Collegiate Technical	—	—	—
B-6310	Collegiate Nontechnical	—	—	—
B-1300	Transfers From Engineering, to:	—	—	—
B-1320	Math/Science	—	—	—
B-1330	Technology	—	—	—
B-1340	Nontechnical	—	—	—
B-1350	Collegiate Technical	—	—	—
B-1360	Collegiate Nontechnical	—	—	—
B-1400	Dropouts	—	—	—
B-1500	B.S. Graduates, to:	37.8	43.0	58.7
B-1510	Engineering Ph.D. Programs	—	—	0.6
B-1520	Math/Science Ph.D. Programs	—	—	—
B-1530	Engineer Pool	—	21.4	38.3
B-1540	Technical Reserve	—	9.3	4.2
B-1550a	Staff Support—Management	—	3.6	4.1
B-1550b	Staff Support—Technical Support	—	5.1	6.5
B-1560	Technician Pool	—	—	—
B-1570	Exit—Home Country	—	—	—
B-1600	M.S. Graduates, to:	7.0	15.5	17.2
B-1610	Engineering Ph.D. Programs	—	—	3.1
B-1620	Math/Science Ph.D. Programs	—	—	—
B-1630	Engineer Pool	—	8.2	9.6
B-1640	Technical Reserve	—	0.8	0.4
B-1650a	Staff Support—Management	—	2.6	1.5
B-1650b	Staff Support—Technical Support	—	1.7	2.0
B-1660	Technician Pool	—	—	—
B-1670	Exit—Home Country	—	—	—

[a] Only full-time students accounted for.

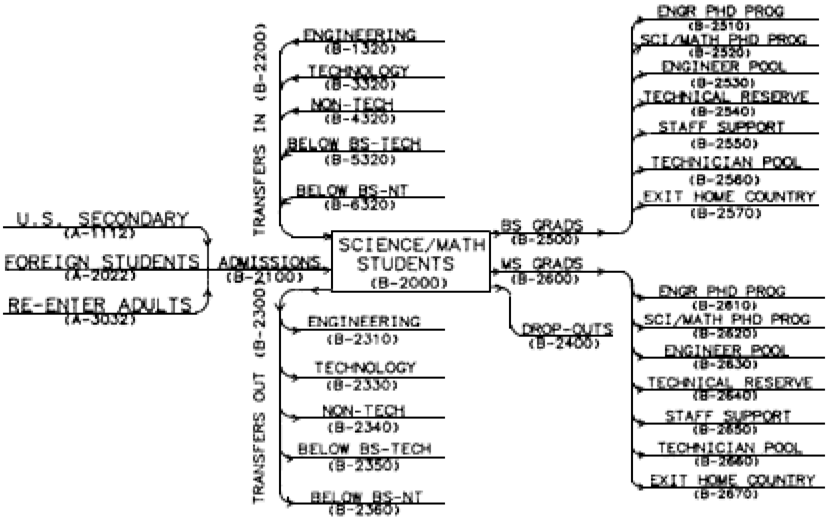


Diagram B-2
Flows affecting science/math students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-2 Flows Affecting Science/Math Students, 1960, 1970, and 1980 (in thousands)

Label	Description	1970	1960	1980
B-2000	Science/Math Students	277.8	485.0	586.3
B-2100	Admissions to Science/Math, From:	92.3	134.9	143.7
A-1112	U.S. Secondary Schools	92.3	134.9	143.7
A-2022	Foreign Students	—	—	—
A-3032	Reentering Adults	—	—	—
B-2200	Transfers to Science/Math, From:	—	—	—
B-1320	Engineering	—	—	—
B-3320	Technology	—	—	—
B-4320	Nontechnical	—	—	—
B-5320	Collegiate Below B.S.—Tech.	—	—	—
B-6320	Collegiate Below B.S.—NT	—	—	—
B-2300	Transfers From Science/Math, to:	—	—	—
B-2310	Engineering	—	—	—
B-2330	Technology	—	—	—
B-2340	Nontechnical	—	—	—
B-2350	Collegiate Below B.S.—Tech.	—	—	—
B-2360	Collegiate Below B.S.—NT	—	—	—
B-2400	Dropouts	—	—	—
B-2500	B.S. Graduates in Science/Math, to:	49.3	100.6	118.2
B-2510	Engineering Ph.D. Programs	—	—	—
B-2520	Science/Math/Technologist/Ph.D. Programs	—	—	—
B-2530	Engineer Pool	—	2.5	3.8
B-2540	Technical Reserve	—	—	—
B-2550a	Staff Support—Management	—	0.6	0.5
B-2550b	Staff Support—Technical Support	—	0.6	0.5
B-2560	Technician Pool	—	—	—
B-2570	Exit—Home Country	—	—	—
B-2600	M.S. Graduates in Science/Math, to:	7.3	17.4	19.1
B-2610	Engineering Ph.D. Programs	—	—	—
B-2620	Science/Math Ph.D. Programs	—	—	5.0
B-2630	Engineer Pool	—	1.0	0.7
B-2640	Technical Reserve	—	—	—
B-2650a	Staff Support—Management	—	0.1	0.1
B-2650b	Staff Support—Technical Support	—	0.2	0.2
B-2660	Technician Pool	—	—	—
B-2670	Exit—Home Country	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

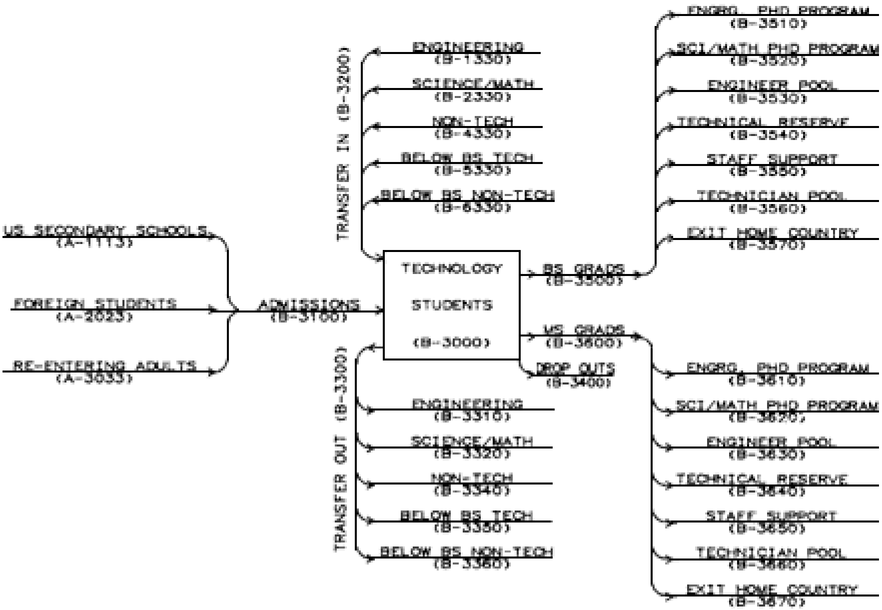


Diagram B-3
Flows affecting technology students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-3 Flows Affecting Technology Students, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
B-3000	Technology Students	—	—	—
B-3100	Admissions to Technology	—	4.8	11.0
A-1113	From U.S. Secondary Schools	—	4.8	11.0
A-2023	Foreign Students	—	—	—
A-3033	Reentering Adults	—	—	—
B-3200	Transfers to Technology, From:	—	—	—
B-1330	Engineering	—	—	—
B-2330	Science/Math	—	—	—
B-4330	Nontechnical	—	—	—
B-5330	Collegiate Below B.S.—Tech.	—	—	—
B-6330	Collegiate Below B.S.—NT	—	—	—
B-3300	Transfers From Technology, to:	—	—	—
B-3310	Engineering	—	—	—
B-3320	Science/Math	—	—	—
B-3340	Nontechnical	—	—	—
B-3350	Collegiate Below B.S.—Tech.	—	—	—
B-3360	Collegiate Below B.S.—NT	—	—	—
B-3400	Dropouts	—	—	—
B-3500	B.S. Graduates in Technology, to:	—	5.2	10. 5
B-3510	Engineering Ph.D. Programs	—	—	—
B-3520	Science/Math Programs	—	—	—
B-3530	Engineering Pool	—	2.4	6.8
B-3540	Technical Reserve	—	1.6	2.5
B-3550a	Staff Support—Management	—	0	0.1
B-3550b	Staff Support—Technical Support	—	0.8	0.8
B-3560	Technician Pool	—	—	—
B-3570	Exit—Home Country	—	—	—
B-3600	M.S. Graduates in Technology, to:	—	0	0.3
B-3610	Engineering Ph. D. Programs	—	—	—
B-3620	Science/Math Programs	—	—	—
B-3630	Engineer Pool	—	—	—
B-3640	Technical Reserve	—	—	—
B-3650a	Staff Support—Management	—	—	—
B-3650b	Staff Support—Technical Support	—	—	—
B-3660	Technician Pool	—	—	—
B-3670	Exit—Home Country	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

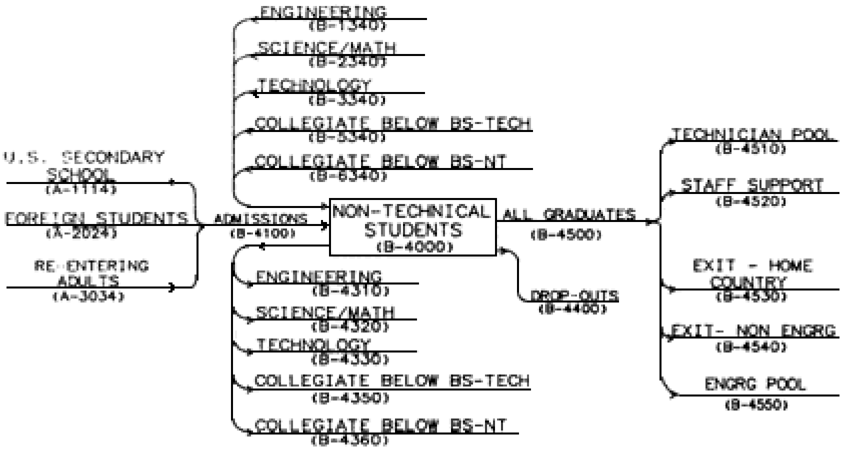


Diagram B-4
Flows affecting nontechnical college students. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-4 Flows Affecting Nontechnical College Students, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
B-4000	Nontechnical College Students	1,580.8	3,490.0	3,631.5
B-4100	Admissions to Nontechnical Studies	460.1	801.6	944.6
A-1114	From U.S. Secondary Schools	460.1	801.6	944.6
A-2024	Foreign Students	—	—	—
A-3034	Reentering Adults	—	—	—
B-4200	Transfers Into Nontechnical, From:	—	—	—
B-1340	Engineering	—	—	—
B-2340	Science/Math	—	—	—
B-3340	Technology	—	—	—
B-5340	Collegiate Below B.S.—Tech.	—	—	—
B-6340	Collegiate Below B.S.—NT	—	—	—
B-4300	Transfers From Nontechnical, to:	—	—	—
B-4310	Engineering	—	—	—
B-4320	Science/Math	—	—	—
B-4330	Technology	—	—	—
B-4350	Collegiate Below B.S.—Tech.	—	—	—
B-4360	Collegiate Below B.S.—NT	—	—	—
B-4400	Dropouts	—	—	—
B-4500	Nontechnical Graduates— All Levels, to:	307.8	649.3	742.0
B-4510	Technician Pool	—	—	—
B-4520a	Staff Support—Management	—	1.8	2.1
B-4520b	Staff Support—Technical Support	—	2.6	1.5
B-4530	Exit—Home Country	—	—	—
B-4540	Exit—Nonengineering	—	—	—
B-4550	Engineering Pool	—	2.6	5.7

NOTE: Tech. = Technical; NT = Nontechnical.

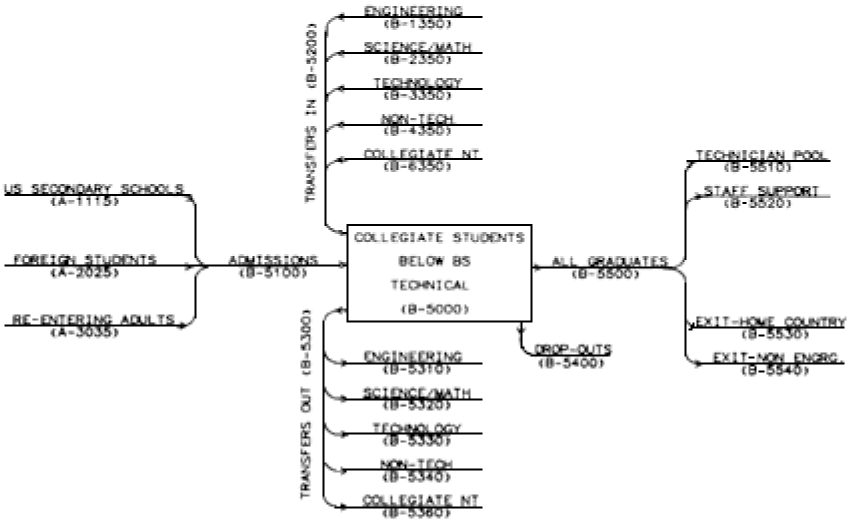


Diagram B-5
Flows affecting collegiate below-B.S. students—technical. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-5 Flows Affecting Collegiate Below-B.S. Students (Technical), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
B-5000	Collegiate Below B.S.—Tech.	35.8	127.0	283.3
B-5100	Admissions	20.2	60.0	150.7
A-1115	From U.S. Secondary Schools	20.2	60.0	150.7
A-2025	Foreign Students	—	—	—
A-3035	Reentering Adults	—	—	—
B-5200	Transfers to College—Tech., From:	—	—	—
B-1350	Engineering	—	—	—
B-2350	Math/Science	—	—	—
B-3350	Technology	—	—	—
B-4350	Nontechnical	—	—	—
B-6350	Collegiate—NT	—	—	—
B-5300	Transfers From College—Tech., to:	—	—	—
B-5310	Engineering	—	—	—
B-5320	Math/Science	—	—	—
B-5330	Technology	—	—	—
B-5340	Nontechnical	—	—	—
B-5360	Collegiate—NT	—	—	—
B-5400	Dropouts	—	—	—
B-5500	All Graduates	—	36.8	68.5
B-5510	To Technician Pool	—	—	—
B-5520a	To Staff Support—Management	—	—	—
B-5520b	To Staff Support—Technical Support	—	—	—
B-5530	Exit—Home Country	—	—	—
B-5540	Exit—Nonengineering	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

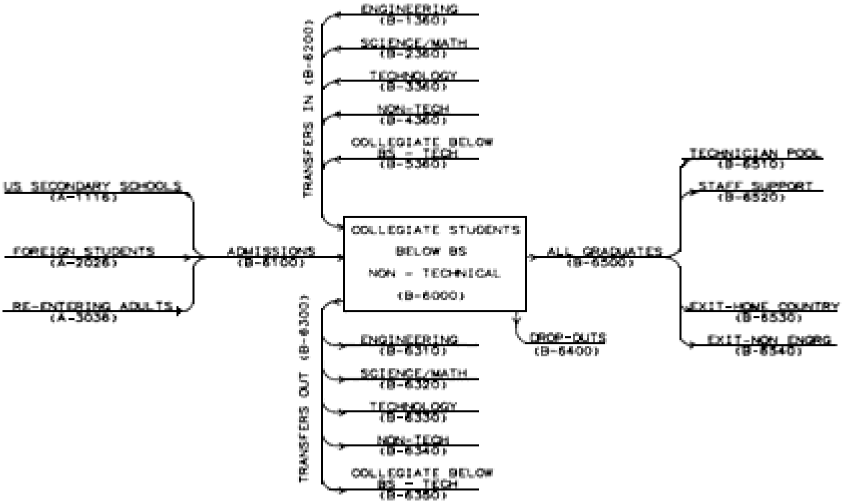


Diagram B-6
Flows affecting collegiate below-B.S. students—nontechnical. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE B-6 Flows Affecting Collegiate Below-B.S. Students [Nontechnical), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
B-6000	Collegiate Students Below B.S.—NT	211.2	748.8	1,393.5
B-6100	Admissions to B-6000	118.8	353.5	748.3
A-1116	U.S. Secondary School	118.8	353.5	748.3
A-2026	Foreign Students	—	—	—
A-3036	Reentering Adults	—	—	—
B-6200	Transfers to B-6000, From:	—	—	—
B-1360	Engineering	—	—	—
B-2360	Science/Math	—	—	—
B-3360	Technology	—	—	—
B-4360	Nontechnical College	—	—	—
B-5360	Collegiate Below B.S.—Tech.	—	—	—
B-6300	Transfers out of B-6000, to:	—	—	—
B-6310	Engineering	—	—	—
B-6320	Science/Math	—	—	—
B-6330	Technology	—	—	—
B-6340	Nontechnical College	—	—	—
B-6350	Collegiate Below B.S.—Tech.	—	—	—
B-6400	Dropouts	—	—	—
B-6500	Graduates Below B.S.—NT	—	216.9	336.9
B-6510	To Technician Pool	—	—	—
B-6520a	To Staff Support—Management	—	—	—
B-6520b	To Staff Support—Technical Support	—	—	—
B-6530	Exit—Home Country	—	—	—
B-6540	Exit—Nonengineering	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

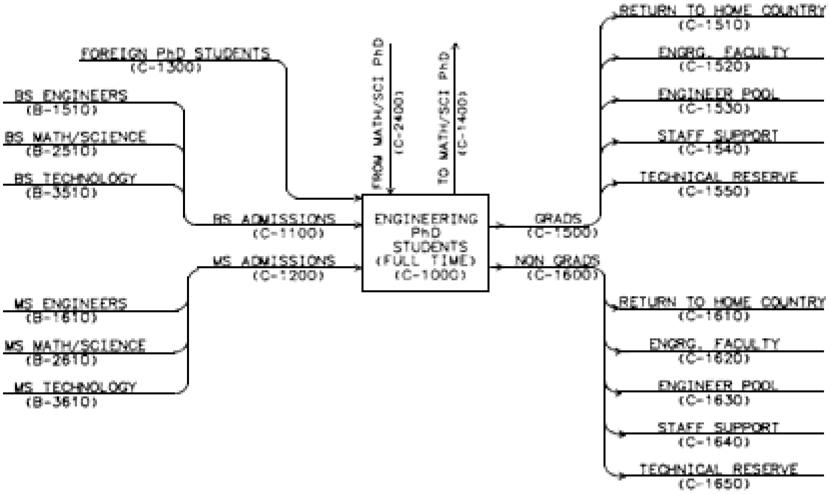


Diagram C-1

Flows affecting engineering Ph.D. students (full time). (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE C-1 Flows Affecting Engineering Ph.D. Students (Full Time), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
C-1000	Engineering Ph.D. Students	5.8	14.8	14.5
C-1100	B.S. Admissions to Engineering Ph.D., From:	—	—	—
B-1510	B.S. Engineers	—	—	—
B-2510	B.S. Math/Science	—	—	—
B-3510	B.S. Technology	—	—	—
C-1200	M.S. Admissions to Engineering Ph.D., From:	—	—	—
B-1610	M.S. Engineers	—	—	—
B-2610	M.S. Math/Science	—	—	—
B-3610	M.S. Technology	—	—	—
C-1300	Foreign Ph.D. Students	—	—	—
C-2400	Transfer From Math/Science Ph.D.	—	—	—
C-1400	Transfer to Math/Science Ph.D.	—	—	—
C-1500	Ph.D. Engineering Graduates	0.8	3.4	2.5
C-1510	Return to Home Country	0.05	0.2	0.24
C-1520	To Engineering Faculty	—	0.79	0.45
C-1530	To Engineer Pool	—	2.06	1.46
C-1540a	To Staff Support—Management	—	0.21	0.24
C-1540b	To Staff Support—Technical Support	—	0.14	0.12
C-1550	To Technical Reserve	—	—	—
C-1600	Leave Ph.D. Program	—	—	—
C-1610	Return to Home Country	—	—	—
C-1620	To Engineering Faculty	—	—	—
C-1630	To Engineer Pool	—	—	—
C-1640a	To Staff Support—Management	—	—	—
C-1640b	To Staff Support—Technical Support	—	—	—
C-1650	To Technical Reserve	—	—	—

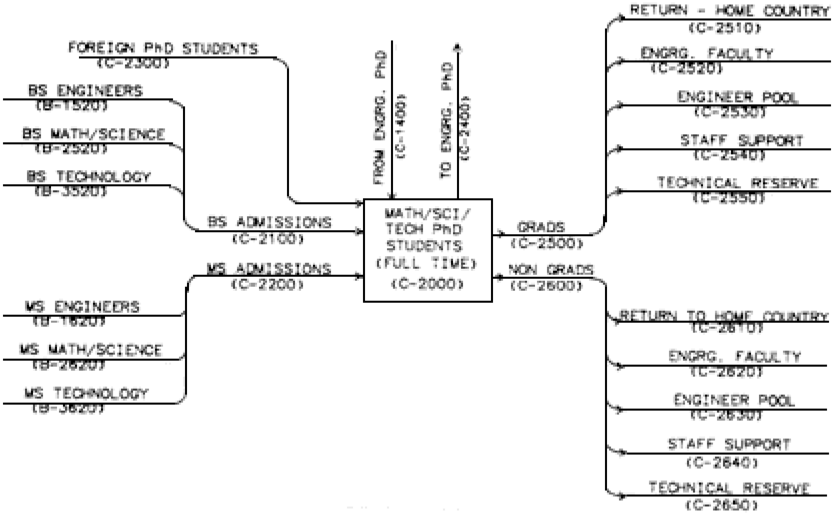


Diagram C-2
Flows affecting math/science/technology Ph.D. students (full time). (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE C-2 Flows Affecting Math/Science/Technology Ph.D. Students (Full Time) 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
C-2000	Math/Science/Technology Ph.D. Students	—	—	—
C-2100	B.S. Admissions to Math/Science Ph.D., From:	—	—	—
B-1520	B.S. Engineers	—	0.5	6.0
B-2520	B.S. Math/Science	—	—	—
B-3520	B.S. Technology	—	—	—
C-2200	M.S. Admissions to Math/Science Ph.D., From:	—	—	—
B-1620	M.S. Engineers	—	2.0	3.1
B-2620	M.S. Math/Science	—	—	5.0
B-3620	M.S. Technology	—	—	—
C-2300	Foreign Ph.D. Students	—	—	—
C-2400	To Engineering Ph.D.	—	—	—
C-2500	Ph.D. Math/Science Graduates	—	—	0.24
C-2510	Return to Home Country	—	—	—
C-2520	To Engineering Faculty	—	—	0.001
C-2530	To Engineering Pool	—	—	0.19
C-2540a	To Staff Support—Management	—	—	0.05
C-2540b	To Staff Support—Technical Support	—	—	—
C-2550	Technical Reserve	—	—	—
C-2600	Leave Ph.D. Program	—	—	—
C-2610	Return to Home Country	—	—	—
C-2620	To Engineering Faculty	—	—	—
C-2630	To Engineering Pool	—	—	—
C-2640a	To Staff Support—Management	—	—	—
C-2640b	To Staff Support—Technical Support	—	—	—
C-2650	Technical Reserve	—	—	—

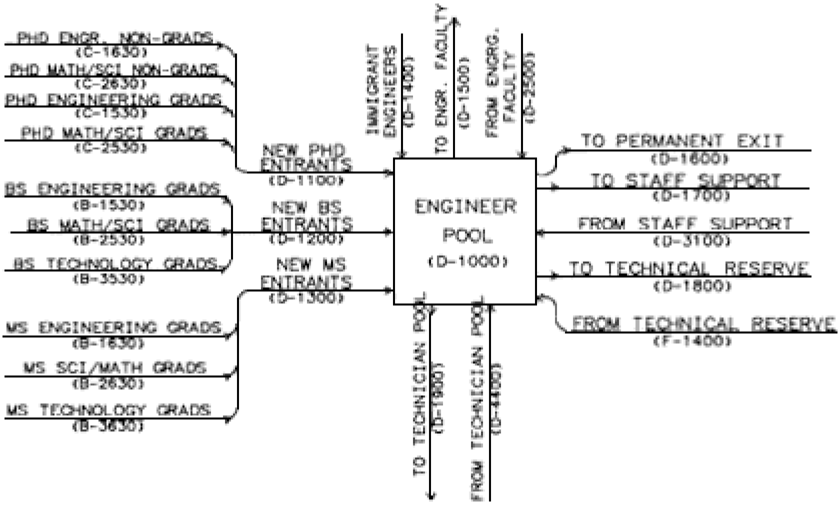


Diagram D-1
Flows of the engineering pool. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE D-1 Flows of the Engineering Pool, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
D-1000	Engineering Pool	326.2	479.5	645.3
D-1100	New Ph.D. Entrants	—	—	—
C-1630	Ph.D. Nongraduates—Engineering	—	—	—
C-2630	Ph.D. Nongraduates—Math/Science	—	—	—
C-1530	Ph.D. Engineering Graduates	—	2.1	1.5
C-2530	Ph.D. Math/Science Graduates	—	—	—
D-1200	New B.S. Entrants	—	28.9	54.1
B-1530	B.S. Engineering Graduates	—	21.4	38.3
B-2530	B.S. Math/Science Graduates	—	2.5	3.8
B-3530	B.S. Technology Graduates	—	2.4	6.8
D-1300	New M.S. Entrants	—	9.2	10.3
B-1630	M.S. Engineering Graduates	—	8.2	9.6
B-2630	M.S. Math/Science Graduates	—	1.0	0.7
B-3630	M.S. Technology Graduates	—	—	—
D-1400	Immigrant Engineers	—	—	—
D-1500	To Engineering Faculty	—	0.5	0.7
D-2500	From Engineering Faculty	—	0.4	0.4
D-1600	Permanent Exit	—	—	8.4
D-1700a	To Staff Support—Management	—	12.5	16.8
D-1700b	To Staff Support—Technical Support	—	9.1	12.3
D-3100a	From Staff Support—Management	—	7.1	10.7
D-3100b	From Staff Support—Technical Support	—	8.1	11.1
D-1800	To Technical Reserve[a]	—	26.4	35.5
F-1400	From Technical Reserve	—	2.7	7.8
D-1900	To Technician Pool	—	—	—
D-4400	From Technician Pool	—	—	—

[a] Does not include retirement.

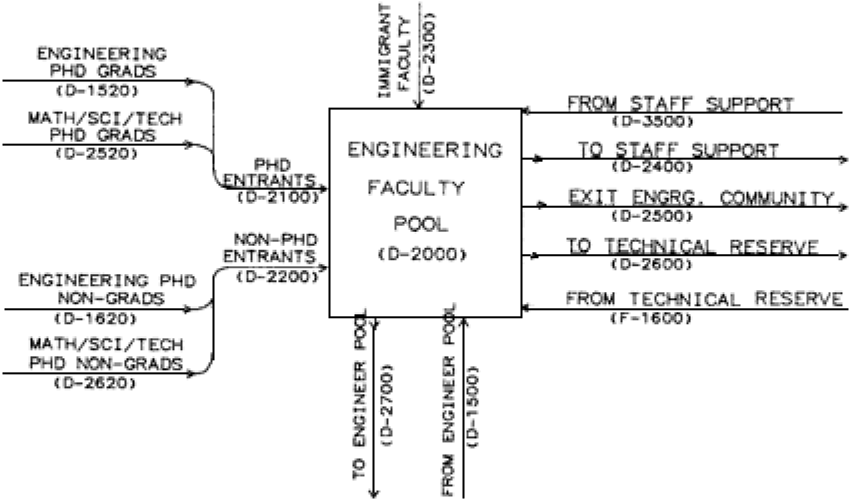


Diagram D-2
Flows of the engineering faculty pool. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE D-2 Flows of the Engineering Faculty Pool, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
D-2000	Engineering Faculty Pool	15.8	17.0	20.3
D-2100	Ph.D.-Degreed Entrants	—	—	—
C-1520	Engineering Ph.D. Graduates	—	0.8	0.5
C-2520	Math/Science/Technology Ph.D. Graduates	—	—	—
D-2200	Ph.D. Nondegreed Entrants[a]	—	0.2	0.2
C-1620	Engineering Ph.D. Nongraduates	—	—	—
C-2620	Math/Science/Technology Ph.D. Nongraduates	—	—	—
D-2300	Immigrant Faculty	—	—	—
D-3500a	From Staff Support—Management	—	0.3	0.4
D-3500b	From Staff Support—Technical Support	—	0.2	0.3
D-2400a	To Staff Support—Management	—	0.4	0.4
D-2400b	To Staff Support—Technical Support	—	0.2	0.2
D-2500	Exit Engineering Community	—	—	0.3
D-2600	To Technical Reserve	—	0.4	0.5
F-1600	From Technical Reserve	—	0.2	0.5
D-1500	From Engineering Pool	—	0.5	0.7
D-2700	To Engineering Pool	—	0.4	0.4

[a] From New M.S. Students in Teaching.

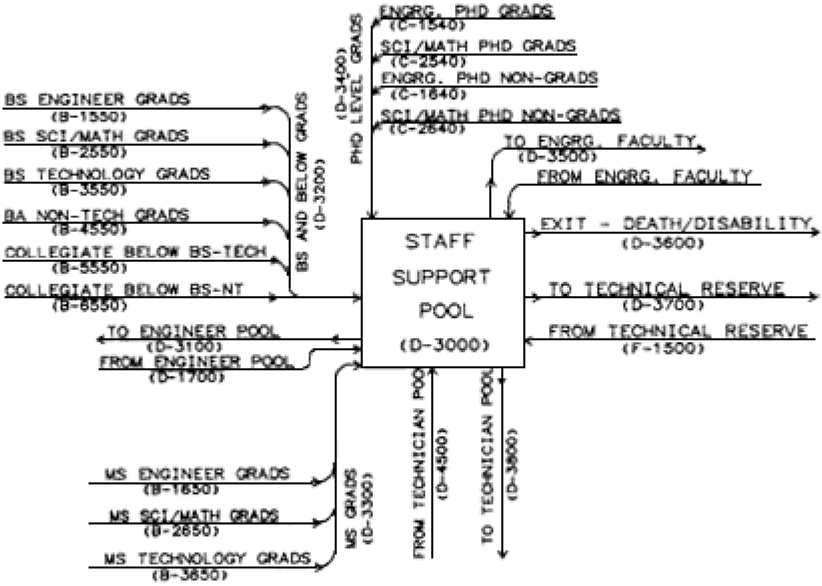


Diagram D-3
Flows of the staff support pool. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE D-3a Flows of the Staff Support Pool (Management), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
D-3000a	Staff Support Pool—Management	213.2	216.5	325.0
D-3100a	To Engineering Pool	—	7.1	10.7
D-1700a	From Engineering Pool	—	12.5	16.8
D-3200a	B.S. and Below-B.S. Graduates, From:	—	—	—
B-1550a	Engineering B.S.	—	3.6	4.1
B-2550a	Science/Math B.S.	—	—	—
B-3550a	Technology B.S.	—	—	0.1
B-4520a	Nontechnical College B.A.	—	1.8	2.1
B-5520a	Collegiate Below B.S.—Tech.	—	—	—
B-6520a	Collegiate Below B.S.—NT	—	—	—
D-3300	M.S. Graduates to Staff Support, From:	—	—	—
B-1650	Engineering M.S.	—	2.6	2.4
B-2650	Science/Math M.S.	—	—	—
B-3650	Technology M.S.	—	0.1	0.1
D-3400	Ph.D.-Level Graduates, From:	—	—	—
C-1540	Engineering Ph.D.	—	—	—
C-2540	Science/Math Ph.D.	—	—	—
C-1640	Engineering Non-Ph.D.	—	—	—
C-2640	Science/Math Non-Ph.D.	—	—	—
D-3500	To Engineering Faculty	—	0.3	0.4
D-2400	From Engineering Faculty	—	0.4	0.4
D-3600	Exit—Death/Disability/Emigration	—	—	4.2
D-3700a	To Technical Reserve	—	18.2	27.3
F-1500a	From Technical Reserve	—	1.9	5.4
D-3800	To Technician Pool	—	—	—
D-4500	From Technician Pool	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

TABLE D-3b Flows of the Staff Support Pool (Technical Support), 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
D-3000b	Staff Support Pool—Technical Support	234.6	180.7	247.6
D-3100b	To Engineering Pool	—	8.1	11.1
D-1700b	From Engineering Pool	—	9.1	12.3
D-3200b	B.S. and Below-B.S. Graduates, From:	—	—	—
B-1550b	Engineering B.S.	—	5.1	6.6
B-2550b	Science/Math B.S.	—	0.6	0.5
B-3550b	Technology B.S.	—	0.8	0.8
B-4520b	Nontechnical College B.A.	—	2.6	1.5
B-5520b	Collegiate Below B.S.—Tech.	—	—	—
B-6520b	Collegiate Below B.S.—NT	—	—	—
D-3300	M.S. Graduates to Staff Support, From:	—	—	—
B-1650	Engineering M.S.	—	1.7	2.0
B-2650	Science/Math M.S.	—	—	—
B-3650	Technology M.S.	—	0.2	0.2
D-3400	Ph.D.-Level Graduates, From:	—	—	—
C-1540	Engineering Ph.D.	—	—	—
C-2540	Science/Math Ph.D.	—	—	—
C-1640	Engineering Non-Ph.D.	—	—	—
C-2640	Science/Math Non-Ph.D.	—	—	—
D-3500	To Engineering Faculty	—	0.2	0.3
D-2400	From Engineering Faculty	—	0.2	0.2
D-3600	Exit—Death/Disability/Emigration	—	—	3.2
D-3700b	To Technical Reserve	—	11.4	15.6
F-1500b	From Technical Reserve	—	1.2	3.4
D-3800	To Technician Pool	—	—	—
D-4500	From Technician Pool	—	—	—

NOTE: Tech. = Technical; NT = Nontechnical.

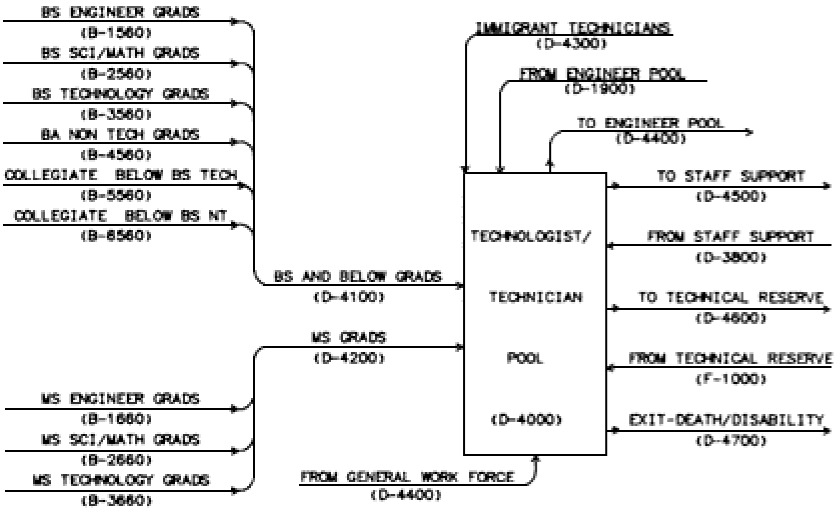


Diagram D-4
Flows of the technologist/technician pool. (See section on "Labeling System for Flow Diagrams" in this appendix.) Note: There are no available data with which to construct a table to accompany Diagram D-4.

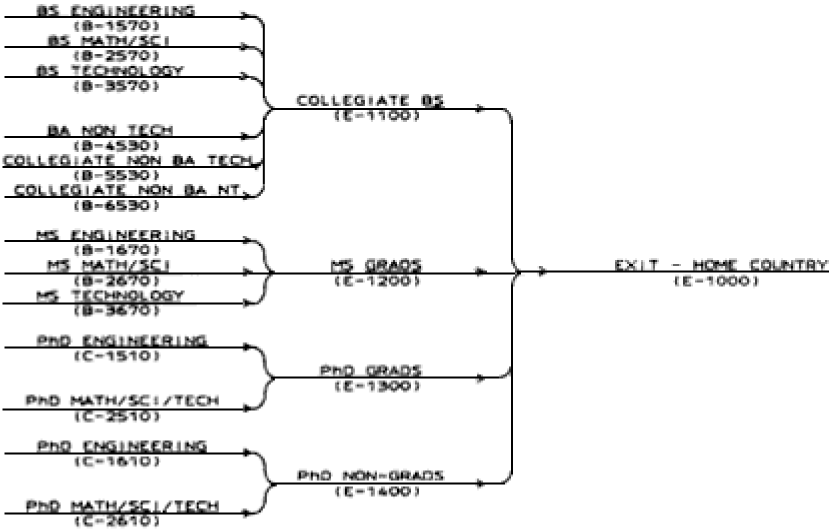


Diagram E-1
Flows of foreign students to home country. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE E-1 Flows of Foreign Students to Home Country, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
E-1000	Student Exit—Home Country	—	—	—
E-1100	Bachelor's/College Exit, From:	—	—	—
B-1570	B.S. Engineering	—	—	—
B-2570	B.S. Math/Science	—	—	—
B-3570	B.S. Technology	—	—	—
B-4530	B.A. Nontechnical	—	—	—
B-5530	College Technical	—	—	—
B-6530	College Nontechnical	—	—	—
E-1200	M.S. Graduates Exit, From:	—	—	—
B-1670	M.S. Engineering	—	—	—
B-2670	M.S. Math/Science	—	—	—
B-3670	M.S. Technology	—	—	—
E-1300	Ph.D. Graduates Exit, From:	—	—	—
C-1510	Ph.D. Engineering	0.05	0.2	0.24
C-2510	Ph.D. Math/Science	—	—	—
E-1400	Ph.D. Nongraduates Exit	—	—	—
C-1610	Ph.D. Engineering	—	—	—
C-2610	Ph.D. Math/Science	—	—	—

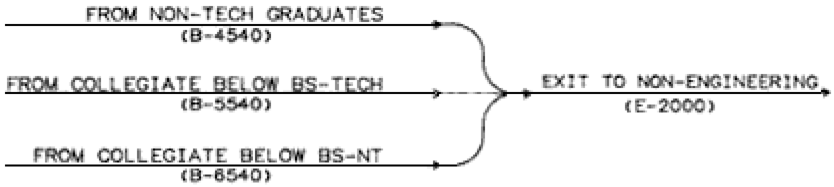


Diagram E-2
Flows of nontechnical and below B.S. out of engineering community. (See section on "Labeling System for Flow Diagrams" in this appendix.) Note: There are no available data with which to construct a table to accompany Diagram E-2.

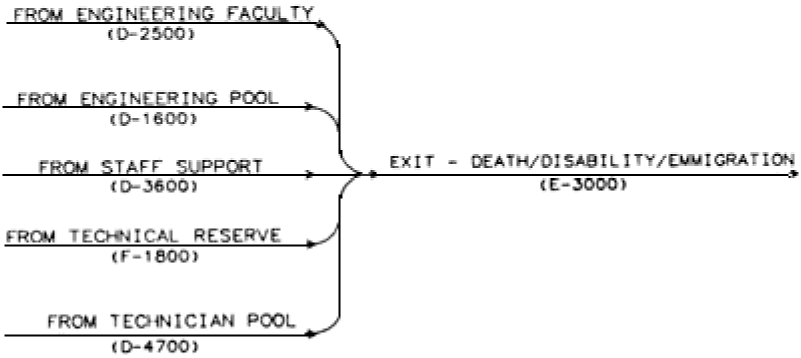


Diagram E-3
Flows out of engineering community from death/disability/emigration. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE E-3 Flows out of Engineering Community From Death/Disability/Emigration, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
E-3000	Exit Engineering Community by Death/Disability/Emigration	—	—	—
D-1600	From Engineering Pool	—	—	8.4
D-2500	From Engineering Faculty Pool	—	—	0.3
D-3600	From Staff Support Pool	—	—	7.4
F-1800	From Technical Reserve	—	—	3.1
D-2700	From Technician Pool	—	0.5	0.6

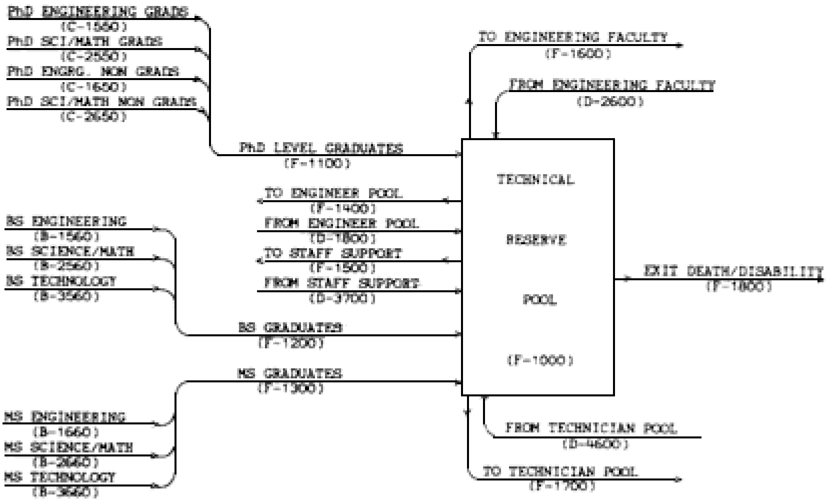


Diagram F-1
Flows of the technical reserve pool. (See section on "Labeling System for Flow Diagrams" in this appendix.)

TABLE F-1 Flows of the Technical Reserve Pool, 1960, 1970, and 1980 (in thousands)

Label	Description	1960	1970	1980
F-1000	Technical Reserve Pool	89.9	91.4	259.0
F-1100	Ph.D.-Level Graduates, From:	—	—	—
C-1550	Ph.D. Engineering Graduates	—	—	—
C-2550	Ph.D. Science/Math Graduates	—	—	—
C-1650	Ph.D. Engineering Nongraduates	—	—	—
C-2650	Ph.D. Science/Math Nongraduates	—	—	—
F-1200	B.S. Graduates to Technical Reserve, From:	—	—	—
B-1560	B.S. Engineering	—	—	—
B-2560	B.S. Science/Math	—	—	—
B-3560	B.S. Technology	—	—	—
F-1300	M.S. Graduates to Technical Reserve, From:	—	—	—
B-1660	M.S. Engineering	—	—	—
B-2660	M.S. Science/Math	—	—	—
B-3660	M.S. Technology	—	—	—
F-1400	To Engineering Pool	—	2.7	7.8
D-1800	From Engineering Pool	—	26.4	35.5
F-1500a	To Staff Support—Management	—	1.9	5.4
F-1500b	To Staff Support—Technical Support	—	1.2	3.4
D-3700a	From Staff Support—Management	—	18.2	27.3
D-3700b	From Staff Support—Technical Support	—	11.4	15.6
F-1600	To Engineering Faculty Pool	—	0.2	0.5
D-2600	From Engineering Faculty Pool	—	0.4	0.5
F-1700	To Technologist/Technician Pool	—	—	—
D-4600	From Technologist/Technician Pool	—	—	—
F-1800	Exit—Death/Disability	—	—	3.1