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ABSTRACT

The nature of undergraduate enrollment in engineering has raised questions about the ability of the United States to retain the leadership necessary to provide for a healthy economy in a technological age. Also, some people are concerned that new graduate enrollments are not keeping pace with the near-doubling of the number of engineering graduates since the mid-1970s and that more than half of doctoral level graduates in recent years have been foreign citizens. Motivation and incentives for U.S. citizens to pursue doctoral degrees in engineering do not apprear to be sufficient. This report proposes ways of thinking about the issues and the effect on the quality of engineering education in the U.S. Chapter 1 introduces the issues; chapter 2 delineates the historical aspects of the study and the demand for engineers in terms of both employment in engineering functions and employment of engineering graduates; and chapter 3 contains conclusions and makes recommendations. Also provided is an executive summary of the findings of this report and extensive appendices including five related tables; the agenda of the August 1987 Workshop on Indicators of the Quality of Performance of Engineers; a list of workshop participants; and seven commissioned papers on the quality and performance of engineers. (CW)

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The Effects on Quality of Adjustments in Engineering Labor Markets

Committee to Study Engineering
Labor-Market Adjustments
Office of Scientific and Engineering Personnel
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1988

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.

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.

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The work of researchers familiar with the issues examined by the committee are also appreciated. First, the committee recognizes the valuable information provided in the papers commissioned for this study and included in Appendix D of this report; seven papers were authored by W. Lee Hansen; James F. Lardner; Robert McGinnis; Russell G. Meyerand, Jr., James R. Bogard, and Stanley A. Brodtman; Alan L. Porter; Gerald I. Susman; and F. Karl Willenbrock. In addition, discussions and presentations by participants at the workshop convened by the committee in August 1987 (see Appendix B) gave direction to what had begun as a rather broad investigation into the engineering labor market and adjustments made to it during the past several decades.

COMMITTEE TO STUDY ENGINEERING LABOR-MARKET ADJUSTMENTS

Harrison Shull, *Chair* (NAS)
Professor of Chemistry
University of Colorado, Boulder

Robert Armstrong
Manager, Professional Staffing
E. I. DuPont de Nemours

Alvin J. Bernstein
Consultant, R&D Productivity
Research and Development Center
General Electric Company

W. Lee Hansen
Professor of Economics
University of Wisconsin, Madison

James F. Lardner (NAE)
Vice President
Deere and Company

Robert McGinnis
Director
Cornell Institute for Social and Economic Research

Russell Meyerand, Jr. (NAE)
Vice President/Chief Scientist
United Technologies Research Center

F. Karl Willenbrock (NAE)
Executive Director
American Society for Engineering Education

Adviser
James Bogard
Manager, Corporate Technology Planning
United Technologies Research Center

Liaison Members
Esther Conwell (NAE)
Research Fellow
Xerox Corporation

Charlotte V. Kuh
Executive Director
Graduate Records Examination Program

Staff
Linda S. Dix
Project Officer

Yupin Bae
Research Assistant

FOREWORD

The cyclic character of undergraduate enrollments in engineering over the past 20 years--from a peak in the mid-1960s to a valley in the early 1970s and back up again to a peak in the early 1980s--has raised many questions regarding the ability of the United States to retain the technological leadership necessary to provide for a healthy and growing economy, an improving quality of life for its citizens, and an adequate national defense. A further concern is that, during and following the recent near-doubling of the number of engineering graduates since the mid-1970s, graduate enrollments, particularly at the doctoral level, have not shown proportionate increases. Also, in recent years more than 50 percent of doctoral-level graduates in engineering have been foreign citizens. There appear to be insufficient motivations and incentives for U.S. citizens to pursue engineering education to the doctoral level.

The issue of the quality of the engineering work force in the United States has been a matter of widespread interest, particularly for recent entrants. Quality of professional personnel, particularly in so diverse and rapidly changing a field as engineering, is exceedingly difficult to define and measure. Anecdotal evidence obtained from most employers of engineers in industry would lead us to believe that the current crop of engineering graduates is the best ever, although there is much disagreement on how they might have been better prepared by their education to meet the needs of various industries. Academic institutions also generally insist that their high standards for faculty are being maintained. At the same time, many university deans and department heads have deplored the fact that they often cannot compete with industry for some of the outstanding new doctoral graduates and are increasingly forced to fill vacant faculty positions, especially at the entry level, with foreign citizens. The implications of these factors for the future character and quality of American engineering eduction is uncertain and is obviously a matter of the utmost importance for the nation.

Finally, the changing demographics of the U.S. population, with the projected decline of the U.S. college-age population and the relative increase within that population of minority groups that traditionally have not provided their proportional share of engineering graduates, may pose additional challenge for the future of the U.S. engineering enterprise.

A study by a committee of the Office of Scientific and Engineering Personnel was undertaken in response to a request from the National Science Foundation to the National Academy of Engineering to explore issues of engineering labor-market adjustments and how they affect the quality of the engineering work force. In this report on the study, the problems and questions discussed above and some others of a more detailed nature are addressed and illuminated to the extent that data were available or could be collected within the time and resource constraints of the study. There are, however, many gaps in the data that could be gathered and in our understanding of the nature and measures of quality in the engineering work force.

The findings and recommendations resulting from the study should assist in the formulation of policies affecting engineering education and labor markets in the near term and in pursuing further many of the issues that must be resolved if we are to meet the challenges of the increasingly competitive technological world of the future.

Alexander H. Flax
Home Secretary
National Academy of Engineering

PREFACE

The National Science Foundation (NSF), through the National Academy of Engineering (NAE), requested the Office of Scientific and Engineering Personnel (OSEP) to undertake an exploratory study of engineering labor market adjustments and their implications for the quality of the engineering work force. The Committee on Engineering Labor-Market Adjustments was appointed to address these issues. This Committee has exercised oversight of the study and has been responsible for the preparation of this report.

The strategy adopted by the Committee was greatly influenced by the very short duration of the study period. The Committee met four times over the course of 10 months. Three briefings were provided to the National Science Board's Committee on Education and Human Resources during this period. OSEP assembled relevant statistics on the employment of engineers in several markets and the changes in their employment patterns over time. In addition, a workshop was convened in August 1987 so that seven commissioned papers could be presented and discussed: three addressed the issue of quality and labor-market adjustments for engineers in academe, industry research and development (R&D) activities, and industry non-R&D activities, respectively; three other papers addressed the issues of performance and its measurement from the point of view of sociology, economics, and industrial organization; the final paper discussed advanced manufacturing technology and its effect on the utilization of engineers (see Appendix D).

This report is structured to propose ways for thinking about the questions on quality that have been raised. Chapter I introduces the issues. Chapter II delineates the historical aspects of the study and of the demand for engineers in terms of both employment in engineering functions and employment of engineering graduates. As will be shown, there are individuals employed in engineering functions who are not formally trained, or in some cases not even recognized, as engineers. In addition, not all engineering graduates at all levels of education are universally employed in engineering functions; some use their engineering skills in nonengineering jobs. The third chapter addresses the specific issues of quality that arise from the response of employers and employees, both in the short run and the long run, to fluctuations in the market for engineers. It also looks specifically at traditional adjustment mechanisms in the markets for engineers and their effect on the quality of engineers. The final chapter draws specific as well as general conclusions and makes recommendations.

EXECUTIVE SUMMARY

Projected trends have given rise recently to concerns about the quality of engineering education and the effective utilization of engineers (nonacademic) in industry at all levels of the profession. Over the next 5 years, the college-age population will decline and its composition with respect to gender and race/ethnicity will change toward groups with historically low rates of participation in engineering. Unless the traditionally low rates of participation in engineering by women and minorities can be reversed, the demand for engineers may have to be met using nontraditional sources. This may result, therefore, in a diminution in the quality of the engineering work force, further reducing the long-term international competitiveness of the United States.

The Committee on Engineering Labor-Market Adjustments was appointed to address this topic, and it worked to define the issues more precisely so as to be able to focus attention on what it believed to be the critical elements of the problem. The Committee chose to explore the effects of plausible market adjustments to perturbations in either the supply of or the demand for engineers upon the quality of "active" engineering performance (i.e., it excluded from its consideration those with engineering skills who were not actively engaged in work requiring use of these skills). The Committee hoped that, by systematically examining these effects, it might be able to identify critical junctures in the dynamics of the market place at which appropriate policies could either minimize deleterious loss in quality or enhance prospective quality gains.

Because of the growing complexity of our society—especially the technological changes occurring in industry—the utilization of engineers in a variety of activities has been increasing steadily over the past decade. The heterogeneity of activity greatly complicates the task of assessing those aspects of demand that may be associated with quality. Moreover, the skills required to perform engineering functions effectively may be possessed by a wide range of individuals with widely differing backgrounds and education. Thus, the definitions of "engineer" and "engineering" have been continuing subjects of debate. In addition, some have questioned whether the use of nontraditional sources of engineering talent affects the quality of the engineering work force, giving rise to another concern—that is, how to define "quality" itself.

The Committee was acutely aware of the problems that might arise from the existence of a large number of possible quality attributes and the huge difficulty in measuring quantitatively any of them in a way that would contribute meaningfully to the resolution of the issues outlined earlier in the limited time frame of this study. On balance, therefore, the Committee chose to be less prescriptive about detailed primary quality attributes in favor of emphasizing the aspects of quality pertinent to international competitiveness--that is, engineering productivity, cost-effective manufacturing, and product reliability.

Data compilation was undertaken with the objective of determining how the engineering labor market has adapted in the past to continuous, long-term increases in demand and how that adaptation process has affected the characteristics of the engineering work force. The analysis concentrated on the 1972-1984 time period.

Findings

Job Openings

Job openings can arise from growth in employment (hereafter referred to as "new" demand) and from separations occurring because of death, retirement, or movement from engineering to other fields (hereafter referred to as "replacement" demand). The Committee examined estimates of job openings arising from each of these factors over the past 15 years and found that:

- The number of total job openings--the sum of new demand and replacement demand--averaged between 125,000 and 185,000 per year.
- New demand created approximately 95,000 jobs annually during this period.
- Attrition, estimated at an annual rate that ranged between 2.0 and 5.5 percent for engineers, produced from 30,000 to almost 90,000 job openings per year.
- The changing age composition of the engineering work force is likely to increase the amount of attrition from death and retirement in the future.

Sources of Supply

The Committee also examined the various sources of supply that were used to fill these job openings. It found that:

- The annual number of new engineering degrees produced at all degree levels fell short of the annual number of engineering job openings, but the gap between job openings and degrees narrowed over time. Degree production responded to employment changes, but with a lag. Degree production reversed its downward trend in 1976 and began to grow rapidly after 1978.

- Nontraditional sources of supply—that is, sources other than new U.S. degree recipients in engineering—were used to fill the gap between job openings and new degrees.
- A significant nontraditional source of supply was individuals with degrees in closely related fields (e.g., chemistry, physics, mathematics). The number of engineers with degrees in nonengineering fields rose from roughly 130,000 in 1972 to approximately 410,000 in 1982. This may have had adverse implications for meeting important national needs involving members of these fields, particularly at the doctorate level. The siphoning of these students into engineering may have been partially responsible for the lack of increase in Ph.D. degree production exhibited by these fields in recent years.
- A second important nontraditional source was foreign-born engineers. The percentage of the engineering work force who are foreign-born rose from almost 10 percent (about 90,000) in 1972 to 19 percent (about 395,000) in 1982. Foreign-born engineers are heavily concentrated among engineering doctorates: the percentage of foreign-born engineers having doctorates is almost double the percentage of foreign-born engineering baccalaureates. Foreign-born engineers comprise a high and growing share of this country's engineering faculty.
- Another potentially important nontraditional source of supply for engineers, particularly in industrial non-R&D activity, is the pool of nondegreed technicians who are promoted to engineering activity on the basis of their experience. Unfortunately, the Committee did not have available to it estimates of the fraction of the engineering work force that consists of such nondegreed individuals.
- In-service training of engineers recruited from other disciplines and continuing training of career engineers can be important to filling job openings effectively since they enable firms to fill openings with minimum loss in performance and they expand the available supply by extending the amount of time career engineers can spend performing engineering functions. Unfortunately, little hard data exist to document the extent to which these training mechanisms are used and their effectiveness in allowing firms to meet their recruitment needs.

Quality

- Many practitioners from industry consulted by the Committee did not believe that the need to fill job openings with individuals recruited from nontraditional sources resulted in an immediate reduction in the quality of the engineering work force. Although meeting the need in this way involved some costs for in-service or career training, the costs were not believed to be significant. Moreover, these costs may partially be offset by the lower salaries frequently paid to engineers with degrees in other disciplines. The Committee emphasizes, however, that this conclusion is based largely on impressionistic evidence rather than on hard data.

- Some practitioners from academe believe that the growing need to fill faculty positions with foreign-born engineers is not a major cause for concern. By and large, these new faculty members are strong in their research capabilities, although concerns were expressed about possible limitations that might exist in the teaching capabilities of some because of language difficulties or cultural attitudes. Here again, the Committee wishes to emphasize the impressionistic nature of this evidence.
- The Committee strongly believes that the growing prominence of the foreign-born on engineering faculties is symptomatic of a more fundamental problem: the apparent unwillingness of American engineering students to choose careers in engineering that require the doctorate.

The Future

- Production of new engineering baccalaureates is expected to peak in 1986. Based on current trends in engineering freshman enrollments, the number of bachelor's degrees produced in the year 1990 is expected to decline from its 1986 peak to 1983 levels. Whether the downward trend will be reversed beyond 1990 will depend on future trends in freshman enrollment. This enrollment is generally sensitive to perceived employment opportunities and business conditions.
- The number of job openings arising from attrition is expected to increase over the next 15 years because of the increased number of engineers approaching retirement age. The effect of these anticipated retirements may be partially postponed, however, by the impact of the recently passed congressional bill abolishing mandatory retirement in most occupations and by other factors such as the improved health condition of our population.
- Job openings arising from growth in engineering employment can be expected to continue, although several factors--such as recent downsizing of technical work forces by a significant number of large firms in response to competitive pressures and recent technological developments in the areas of computer-assisted design, computer-assisted manufacturing, and artificial intelligence--may operate to damp employment growth rates.
- Given the experience of the last 15 years and expectations about the next 15 years, the Committee concludes that the need for engineers will continue to be met in part by reliance on nontraditional sources of supply and in part by more

effective utilization of the experienced engineering talent pool.

Recommendations

Based on these findings, the Committee offers the following recommendations:

- Both the Administration and the Congress should take steps to assure that the recruitment of foreign engineers is not made more difficult than it is now. These engineers are an essential source of supply, especially to academe, and can be expected to continue to be such a source until more American students are persuaded to pursue doctorates in engineering.
- Steps should be taken to encourage more American students to pursue doctorates in engineering. One promising mechanism for achieving this objective is to increase the number and stipend size of fellowship and assistantship support provided by the federal government. Another is to increase the amount and quality of equipment available on campuses for engineering research. Yet another is to reduce the amount of effort and the range of uncertainty that exist in securing federal research support. Finally, industry should reinforce the importance of graduate education for U.S. students by providing rewarding job opportunities and careers to engineers having graduate degrees.
- Steps should be taken to deepen the pool of students with the backgrounds necessary for pursuing careers in either science or engineering. Important mechanisms for achieving this objective include (a) improvement in the amount and quality of science and mathematics education given to students in elementary and high school and (b) encouragement of an increasing number of students who are women or members of underrepresented racial/ethnic minority groups to select engineering as their careers.
- Federal policy should be conducive to the continued and more extensive use of in-service and continuing career training by industrial firms. Engineering societies should consider requiring continued education for professional engineers to retain their licenses.
- Federal policy should encourage the adoption of information technology in engineering functions in order to be able to make more effective use of the existing engineering work force.

The Committee feels that a considerable amount of fundamental research will be necessary before creditable indicators of engineering productivity will be available and before the determinants of engineering productivity are better known and their impacts more fully understood. The paucity of solid data required to assess the qualitative implications of market responses to increases in the demand for engineers limited the scope of the Committee's examination. Thus, the Committee recommends the following topics for further research:

- More information and research is needed about the utilization of engineers in industry. Little is known at the present time about the impact of measures taken to improve industrial competitiveness on the activities and the productivity of engineers.
- More research should be conducted on the determinants of retirement and career choice decisions in order to understand better the implications of existing and future demographic patterns.
- More information is needed about the extent and impact of in-service and continuing training programs and how they interact with the rapidity with which skills, learned while acquiring the engineering degree, become obsolete.
- Our ability to formulate effective policy with respect to the education and utilization of engineers requires better understanding of current and future job openings, their determinants, and the types of skills required to fill them effectively. Our inability to compile appropriate information to illuminate key issues arises in large part from the sporadic and discontinuous attention that has been given to them in the past.
- We should learn more about the management of the engineering function in industry, the incentives applied to encourage better engineering education, and the applicability of postgraduate engineers in industry. Case studies of these topics would be appropriate.
- Computer science and engineering manpower data should be more carefully prescribed and collected.
- More information is needed on individuals who do engineering work but who have no engineering degrees. Special studies of this group would be worthwhile.
- The Committee recommends deeper studies of the quality of engineering work produced by degreed engineers as compared to that of nondegreed workers. The feasibility of such studies should be assessed. Some comparative international data may be available, and further studies in these areas should be stimulated, especially in view of the concerns over international competition. The relative number of engineers used by our strongest industrial competitors should also be studied.

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I. THE PROBLEM

The recent National Research Council study, *The Impact of Defense Spending on Nondefense Engineering Labor Markets,* assessing the effect of defense expenditures on demand and supply for engineers, concluded that there was no evidence of a deleterious effect on the civilian sector from the expanded defense needs for engineers in recent years. That report, however, did not address a related critical issue --whether the defense sector, with its economic advantages of plentiful funds and the attractiveness of its state-of-the-art research and development (R&D), might have induced an undue share of "the best and the brightest" to join it, leaving civilian enterprises to suffer from less creative talent. Earlier studies had also concluded that shortages were not a major problem but had raised questions about the quality of engineering education and the effective utilization of engineers in industry (nonacademic) at all levels of the profession.[1]

Over the next 5 years, the college-age population will decline, and its composition with respect to gender and race/ethnicity will change toward groups with historically low rates of participation in engineering careers. As a result, the supply of engineers graduating from college may also decline, perhaps quite markedly. There is concern, therefore, that unless the traditionally low rates of participation in engineering by women and minorities can be reversed, the demand for engineers may have to be met using nontraditional sources. This may result, therefore, in a diminution in the quality of the engineering work force, further reducing the long-term international competitiveness of the United States.

In the face of a shortage in the supply of traditional engineers --that is, U.S. citizens who have degrees in engineering fields--indus-

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[1] See Committee on the Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985. Other recent publications--for example, the Government-University-Industry Research Roundtable's *Nurturing Science and Engineering Talent: A Discussion Paper,* Washington, D.C.: National Academy of Sciences, 1987, and those from the Office of Technology Assessment and the National Science Foundation's Division of Policy Research and Analysis--have also discussed these issues.

try turns to other sources of supply. For example, companies hire an increasing number of non-U.S. citizens, or they hire individuals with nonengineering degrees (particularly those in closely related physical science fields) and cross-train them in those aspects of engineering that can be easily assimilated, or they upgrade technicians to do engineering work. Does this use of nontraditional sources affect the quality of the engineering work force? The answer to this question will depend on a number of factors, including (1) the definition of quality, (2) the assessment of particular engineering functions and skill requirements, (3) the depth of the pool from which these nontraditional sources of supply are drawn, (4) the quality of the on-the-job training, and (5) the ability of our educational system to adjust to variations in engineering activities and skill requirements over the long run.

The Committee recognized at the outset that the issue of quality and how it might be affected by labor-market conditions is extraordinarily complex and involves factors that are, by their nature, highly subjective. It, therefore, worked to define the issues more precisely so as to be able to focus attention on what it believed to be the critical elements of the problem. Three issues needed attention in this connection: the definition of an engineer used in this report, identification of relevant factors of quality, and delineation of the types of labor-market adjustments to be considered. Putting these three items--the engineer, the quality of the engineer, and market adjustments--together, the Committee chose to explore the effects of plausible market adjustments on the quality issues related to "active" engineering performance. If one looks at these effects systematically, it may be possible to identify critical junctures in the dynamics of the market place at which appropriate policy inputs can either minimize deleterious loss in quality or enhance prospective quality gains. Thus, the Committee's goal was not to catalog the events, but rather to focus on policy implications in the hope that a better understanding of these events would improve the ability to formulate effective actions for improving productivity, stimulating new product innovation and development, containing costs, and ultimately enhancing the international competitive position of the United States.

Defining the Engineer

Because of the growing complexity of our society--especially the technological changes that are occurring in industry--the utilization of engineers has been increasing steadily over the past decade. The demand for engineering skills, however, is spawned by a wide variety of activities that has broadened the range of skills considered as engineering. Thus, engineering is not a homogeneous activity, and the engineer is not a homogeneous bundle of skills. Engineers perform as professionals applying their skills in the manufacturing sector on the factory shipping dock; on the factory floor in product testing and refinement, design, new product innovation, and application research based on new technologies; and the discovery of new fundamental knowledge. Engineering support is necessary in quality control, statistical analyses, marketing functions, sales, and service of installed equipment and systems. In the nonmanufacturing sectors (such as electric utilities, communication systems, and transportation systems), as well as in the government and military, engineering skills are important in design, construction, maintenance, scheduling, and operation. In academe, engineers devote their professional expertise to pursuits in educating future engineers and developing new knowledge in research laboratories. This heterogeneity of activity and the diversity of the skills required to undertake these activities greatly complicate the task of assessing those aspects of demand that may be associated with quality.

The skills required to perform engineering functions effectively may be possessed by a range of individuals with widely differing backgrounds and education. The supply of individuals in engineering can encompass some individuals trained as technicians; those who received engineering degrees at the bachelor's (the normally accepted professional degree), master's, and doctorate levels; some educated in related disciplines such as physics, chemistry, or mathematics; and some who receive on-the-job training within businesses and industry. The supply of engineers from U.S. colleges and universities has shown cyclical variations over the past several decades around a generally increasing trend. These shifts appear to be the result of shifts in the industrial demand for engineers and the associated expectations of entering students with respect to job opportunities and salaries some years in the future.[2]

The definition of an engineer has been a continuing subject of debate. The National Science Foundation has, for purposes of its data reporting efforts, defined an engineer as one who (1) has an engineering degree, and/or (2) is performing an engineering function, and/or (3) is professionally identified (self-identified) as an engineer based on total education and work experience. This all-encompassing definition of an engineer is convenient in collecting, aggregating, and reporting data. The resulting aggregation, however, can include many who call themselves engineers but who are no longer actively involved in engineering work.

An alternative source of information, the Bureau of Labor Statistics, collects data describing those who report employment in an engineering occupation. Estimates of the number of engineers derived from these data are likely to be too narrowly circumscribed. They will exclude individuals with engineering degrees who are employed in nonengineering occupations that require engineering skills--for example, occupations that are a part of managerial, marketing, or production activities. The Committee estimates that anywhere from 30 to 70 per-

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[2] Glen Cain, Richard B. Freeman, and W. L. Hansen, *Labor Market Analysis of Engineers and Technical Workers,* Baltimore: Johns Hopkins University Press, 1973.

cent of those with degrees in engineering are performing jobs that are not classified as engineering jobs.[3]

The Committee modified NSF data to conform to a different definition of an "active" engineer, adapted from the earlier report by the Committee on the Education and Utilization of the Engineer:

> *Active Engineer:* A person meeting at least one of the following conditions:
>
> - actively engaged in engineering,
> - actively engaged in engineering education,
> - qualified as an engineer and actively engaged in such functions as engineering, engineering management, or engineering administration,
> - registered or licensed as an engineer by a government agency, or
> - currently or recently employed in a job classification requiring engineering work at a professional level

where "engineering" is defined as:

> 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.[4]

The intent was to include only those individuals who contribute constructively to the engineering output of the United States. Thus, for this study, estimates of the number of individuals who satisfied the NSF definition but who also reported that they were employed in scientific or engineering activity were selected as the best available approximation to this concept.[5]

The Quality of the Engineer

The definition of "quality" is even more tenuous than that of the

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[3] See James F. Lardner, "Performance of Scientists and Engineers in Non-R&D Industries," Appendix D.

[4] Committee on the Education and Utilization of the Engineer, *Engineering Infrastructure Diagramming and Modeling,* Washington, D.C.: National Academy Press, 1986, p. 11.

[5] Examination of the data reveals that, for the 1972-1986 period, roughly 7 percent of those classified as engineers by NSF reported that they were not employed in scientific or engineering activities (see Appendix A, Table 1, page 45).

"active" engineer. Quality is a highly subjective concept. One can itemize a long list of potential quality indicators, ranging from measures of individual achievement (e.g., performance on nationally recognized tests, honors, class rank, career development, salary growth, papers published, and patents issued), through academic institutional measures (e.g., quality of student body as a whole, perceived quality of faculty and/or the course of instruction), to characteristics of the employing institution (e.g., evidence of innovation and creativity as expressed in the total of the institution's patents and publications and of success as measured in market share or in product cost and reliability), and finally to international measures (as represented, for example, in international market shares, relative production costs, and perceived quality per price).

At the outset the Committee was acutely aware of the problems that might arise from the existence of a large number of possible quality attributes and the difficulty of measuring any of them meaningfully in the limited time frame of this study. On balance, therefore, the Committee chose to be less prescriptive about quality attributes in favor of emphasizing some of the aspects of quality pertinent to international competitiveness--engineering productivity, cost-effective manufacturing, and product reliability. In particular, the Committee approached the quality issue in terms of the relative cost-effectiveness of filling engineering jobs with workers having alternative bundles of skills.

Market Adjustments

It is helpful to recognize that labor-market adjustments reflect a dynamic process involving a constantly shifting set of individuals and conditions. At any one time, a steady state set of conditions can be defined--conditions that in the absence of unusual market pressures result in a state of approximate balance between the number of individuals seeking employment and the number of positions available. The object of this study has been not to study the total steady-state market in all its complexity, but rather to explore the possible interferences with the steady-state market and the changes forced by any number of possible perturbations leading to a new steady state. These include, for example, economic recession, shifts in national priorities (such as the defense buildup), sizable demographic changes, and the introduction of new technologies resulting in new major priorities (e.g., space) or in new consumer demand (e.g., VCRs and PCs).

A wide variety of possible market adjustments exists to accommodate increases in the demand for engineers. For example, managers can hire more engineers, decide against engineering-intensive projects, go off-shore for engineering talent, tap foreign sources of engineers, hire more Americans to do their engineering work, invest more capital in work stations to amplify output of current staff, and upgrade current scientific and technical personnel. The Committee considered the quality implications of as many market adjustments as was possible in the time available.

Refining the Task

Putting these three items--the engineer, the quality of the engineer, and market adjustments--together, with all the caveats mentioned above, the Committee chose to explore the effects of plausible market adjustments on the quality issues related to "active" engineering performance. It hoped that, by looking at these systematically, it would be possible to identify critical junctures in the dynamics of the market place at which appropriate policies could either minimize loss in quality or enhance prospective quality gains. Thus, the Committee's goal was not to catalog the events, but rather to focus on the quality implications of events in the hope that a better understanding of these events would improve our ability to formulate effective actions for improving productivity, containing costs, and ultimately enhancing the international competitive position of the United States.

II. THE MARKET FOR ENGINEERS: RECENT TRENDS

The data compilation summarized in this chapter was undertaken with the objective of determining how the engineering labor market has adapted in the recent past to changes in demand and how that adaptation process has affected the characteristics of the engineering work force. The analysis concentrated on the time period extending from 1972 to the most recent year for which data were available. This particular period of time was chosen for two reasons:

(1) The data available for this period--especially those compiled by the Division of Science Resource Studies of the National Science Foundation (NSF)--are considered to be well-suited to the analysis of the workings of the engineering labor market; and
(2) It spans a period during which engineering supply and demand changed significantly.

Ideally, it would have been desirable to study both rising and falling markets, but the period examined represents a time of almost continuous strong increase in engineering employment.

Demand for Engineers

There are a variety of ways of defining "demand" in labor markets. Use of total employment as an indicator of demand presented problems to the Committee because, as economic principles of markets suggest, changes in employment can reflect either shifts in a demand function along a given supply function, or shifts in a supply function along a given demand function, or combinations of both. Moreover, use of employment as an indicator of demand assumes either that there are no unfilled job vacancies or that the filled positions all represent employment necessary to the employer.

Given the difficulty of being able to attribute employment changes uniquely either to demand factors or supply factors and given the lack of meaningful data on job vacancies, the Committee concentrated on the number of job openings arising from employment growth and separations from the engineering work force. Job openings arising from growth in employment are henceforth referred to as "new" demand. Separations occurring because of death, retirement, or movement from engineering to other fields produce job openings that will be referred to as "replacement" demand. The Committee examined estimates of these demands over the past 15 years and found that the sum of new demand and replacement demand averaged between 125,000 and 185,000 per year. For a number of methodological reasons discussed below, this range is probably an upper bound on the true number of job openings that occurred annually during this period.

New Demand

New demand for engineers may result from an increase in economic activity--for example, as a concomitant of population growth--and from the growing technical complexity of the nation's industrial structure. The former represents employment growth that arises simply because employers of engineers require more of all resources to produce a larger output. The latter is reflected in increases in the proportion of the employed work force represented by engineers. This latter increase may have occurred either because of a greater need for the problem-solving skills and training of engineers or because more engineers were available through increased supply, and these individuals are attractive resources for many kinds of work.

Employment of engineers rose substantially from 1972 to 1986. According to NSF data, employment increased from almost 900,000 to over 2.2 million, an average growth rate of almost 7 percent per year (Figure 1).[6] Employment growth averaged over 8 percent per year for the 1972-1978 period; it dropped to 6.3 percent per year for the 1978-1984 period and to 4.2 percent per year for the 1984-1986 period. Based on these data, the Committee estimates that new demand created an average of approximately 95,000 jobs annually for the years 1972-1986.[7]

Replacement Demand

Attrition, estimated at an annual rate that ranged between 2.0 and 5.5 percent for engineers, produced from 30,000 to almost 90,000 job openings per year. The Committee estimated that, depending on whether movement to administrative occupations was treated as a movement out of

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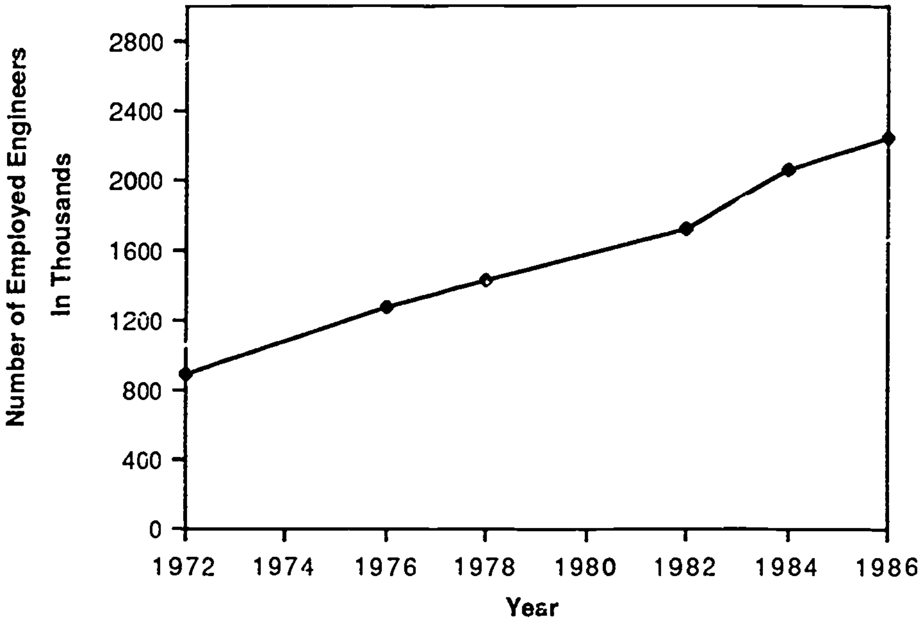
[6] This estimate of employment growth is based on estimates of the number of employed engineers (using NSF's broader definition of engineer) who reported that they were working in a position that was related to science or engineering.

[7] The Bureau of Labor Statistics (BLS) reported a much smaller increase in engineering employment--about 600,000 from 1972 to 1985. This represented an average annual growth rate of 3.1 percent. The rate was slightly faster between 1977 and 1980--3.6 percent; it was much slower from 1980 to 1985--2.1 percent. As noted in Chapter I, however, the BLS estimates are based on a much narrower, occupational concept. They are therefore not comparable to the less restrictive NSF estimates.



NOTE: See Appendix Table 1, page 45.

Figure 1. Employment of engineers, selected years, 1972-1986.

engineering, roughly 1.0 to 4.5 percentage points of this annual rate of attrition were separations caused by the outflow of engineers to other occupations[8] and assumed that 1 percent were separations due to death or retirement.

The Committee believes, however, that the method used to develop these estimated rates makes the 5.5 percent estimate an upper bound to the actual rate of separation. These rates of occupational separation are likely to overstate attrition for two reasons. The first applies particularly to engineers who report that they have moved to nonengineering occupations in which their responsibilities require engineering skills (e.g., managing R&D activity). Although such individuals should not be counted as separations from engineering, they are so classified if they report their new occupations as nonengineering ones. The second reason is methodological. Occupational changes can also reflect reporting error with respect to the occupational item on the survey questionnaire, rather than true occupational mobility.

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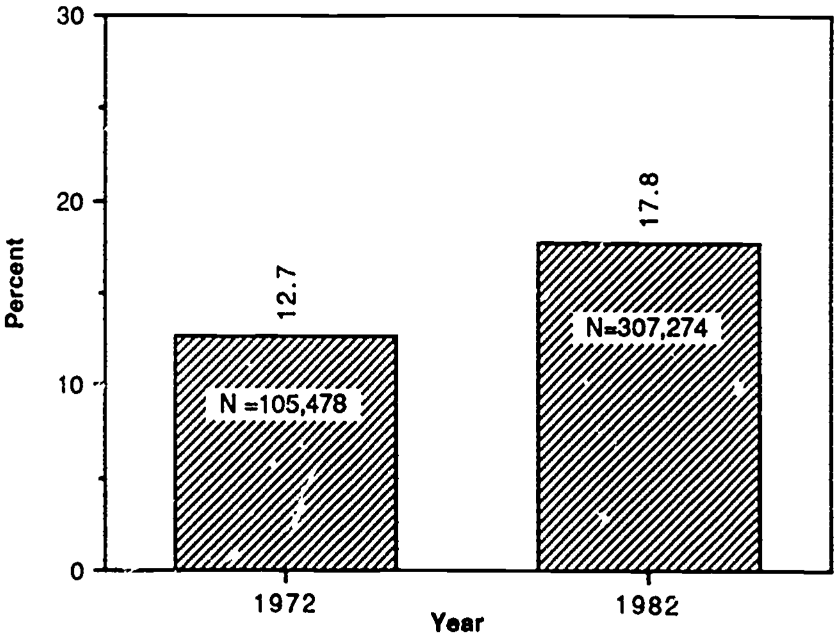
[8] The separation rates were derived from the National Science Foundation's *Study of Occupational Mobility of Scientists and Engineers* (NSF 80-317), Washington, D.C.: U.S. Government Printing Office, 1980, for the period 1972-1978 and from unpublished OSEP tabulations of the NSF sample of experienced scientists and engineers. If movements to administrative occupations are included in the estimates of attrition, the former reports an estimated occupational mobility rate of 4.25 percent while the latter produces an estimated rate of 4.6 percent. If these movements are excluded, the rate drops to approximately 1 percent.



NOTE: See Appendix Table 2, page 45.

Figure 2. Percentage of employed engineers who were 55 and over, 1972 and 1982.

The changing age composition of the engineering work force is likely to increase the amount of attrition from death and retirement. The fraction of this work force above the age of 55 increased from 12.7 percent to 17.8 percent between 1972 and 1984 (Figure 2). This increase in the proportion of older engineers, together with the greatly increased size of the engineering work force, suggests that the number of separations from the engineering work force due to retirement is likely to increase dramatically during the next decade. Therefore, replacement demand is expected to rise sharply in the years ahead.

Supply of Engineers

New Degrees[9]

The annual number of new engineering bachelor's degrees declined from 1972 to 1976 but increased dramatically (at an average annual rate of more than 7 percent) between 1976 and 1985 (Figure 3).

The demographic changes that occurred over this period appear not

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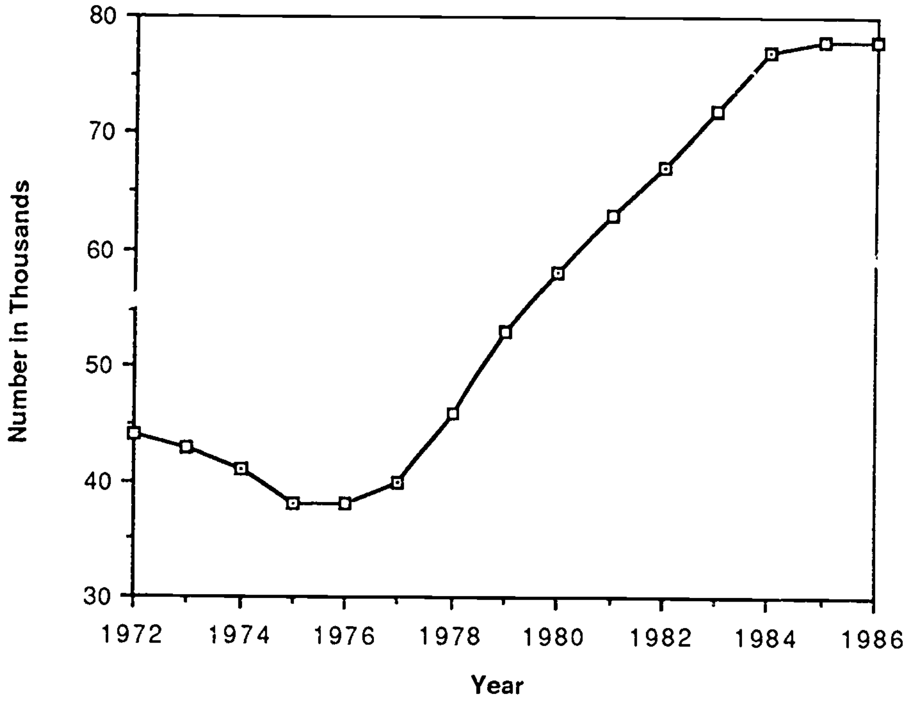
[9] The analysis of new degrees is restricted to engineering baccalaureates in order to avoid double-counting of those bachelor's recipients who ultimately acquire degrees in engineering at the master's and doctorate levels. This restriction results in some understatement of new postgraduate degrees received by individuals with undergraduate degrees in nonengineering fields.



NOTE: See Appendix Table 3, page 46.

Figure 3. Total number of bachelor's degrees in engineering granted, 1972-1986.

to have been the major influences on the supply of new engineering degrees--particularly at the bachelor's degree level. Other factors operated to increase the share of the talent pool taking degrees in engineering. One of these nondemographic factors was an increase in estimated college enrollment rates. The number of college enrollments per 100 18- to 21-year-olds rose from 59 in 1972 to 81 in 1986 (see Figure 4).[10] Another nondemographic factor was an increase in the percentage of college freshmen who are enrolled in engineering programs. This percentage rose from 2.4 in 1972 to 4.5 in 1985 (see Figure 5).

The Committee notes that the rate of increase in engineering bachelor's degree production was greater than the rate of increase in bachelor's degree production for all fields. Thus, engineering increased its share of total degree production at this degree level. The Committee believes that some fraction of this increase may have come from

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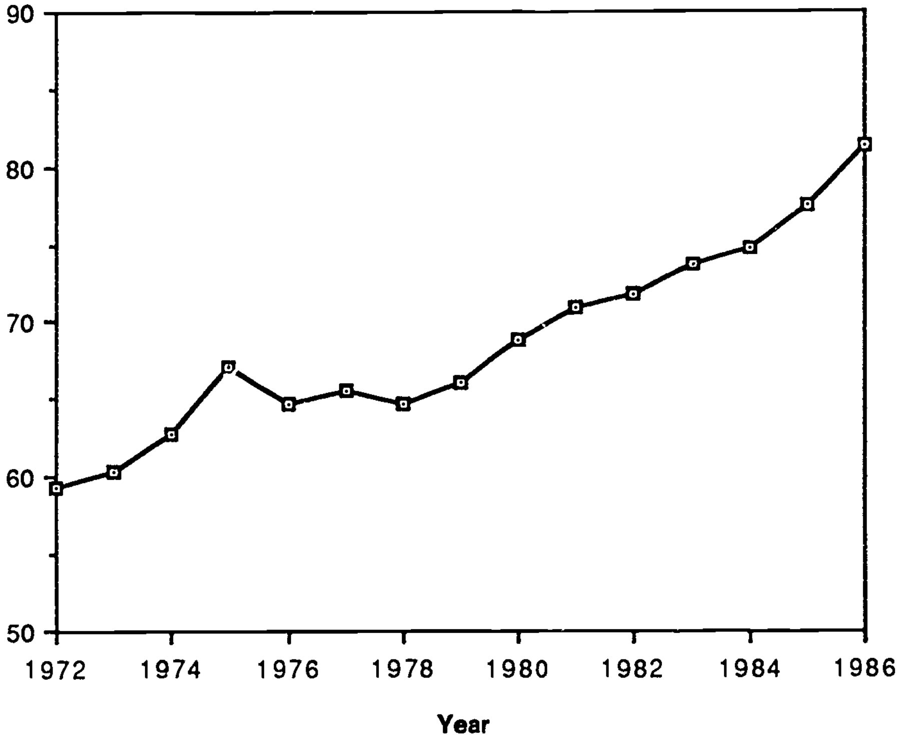
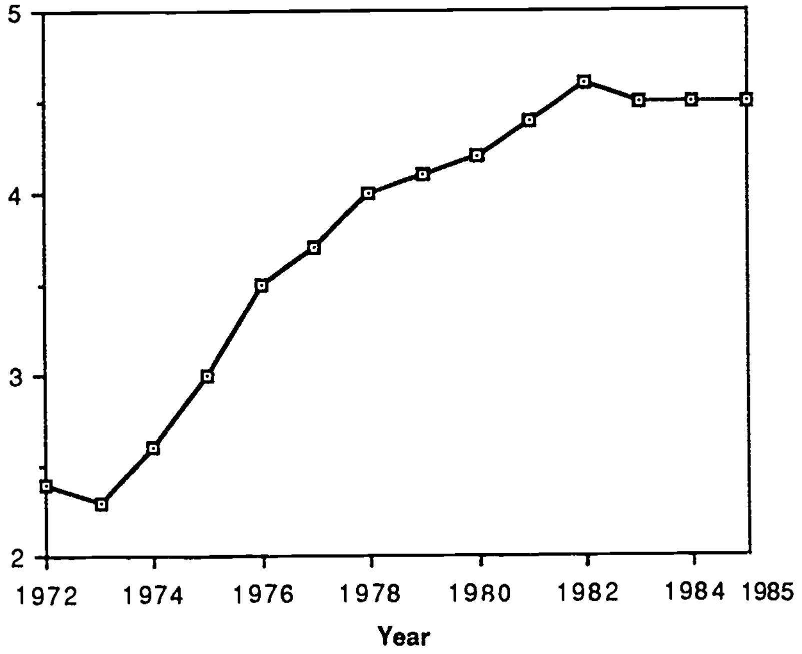
[10] Evidence supporting the conclusion that college enrollment rates were rising can be seen in the "college continuation rates," estimated as the number of first-year college enrollments per 100 high school graduates in the preceding year. This ratio rose from 75 in 1972 to 83 in 1984. Thus, although the number of high school graduates has declined substantially since 1972 (particularly since 1981), first-year college enrollments have risen slightly over the period (although they have been declining since 1981).



NOTE: See Appendix Table 3, page 46.

Figure 4. College enrollment per 100 18- to 21-year-olds, 1972-1986.



NOTE: See Appendix Table 3, page 46.

Figure 5. Engineering freshman enrollment per 100 first-year undergraduate enrollees, 1972-1985.

students who would otherwise have acquired degrees in closely related fields of science--for example, chemistry, physics, and mathematics.[11] Since a large fraction of the doctorates granted in these science fields are awarded to individuals who took their undergraduate degrees in the same fields, the ability to fill the engineering job openings by increasing the number of new engineering bachelor's degrees may have come at the immediate expense of bachelor's production and, subsequently, doctorate production in closely related science fields.

Freshman engineering enrollment is a strong harbinger of engineering bachelor's degree production (see Figure 6 and Appendix Table 3). About 93 percent of the variation in engineering bachelor's degree production between 1972 and 1986 was associated with variations in freshman engineering enrollments, 1968-1982. Based on these enrollment trends, therefore, the Committee expects engineering bachelor's degree production to have peaked in 1986, after which it will decline until at least the end of this decade.[12]

The Committee also notes that, despite the significant increase that has occurred in engineering degree production, important indicators of academic achievement for engineering students--high school grade-point averages (GPAs) and Graduate Records Examination (GRE) scores[13]--have not displayed strong downward trends during this period, although high school grades declined between 1978 and 1984 (Table 1) and may now have stabilized.

One implication that emerges from the analysis summarized above is that, for the period 1972-1984, the average annual numbers of job openings for engineers exceeded average annual production of newly degreed engineers. Thus, these job openings must have been filled by relying on nontraditional sources of supply (e.g., individuals with nonengi-

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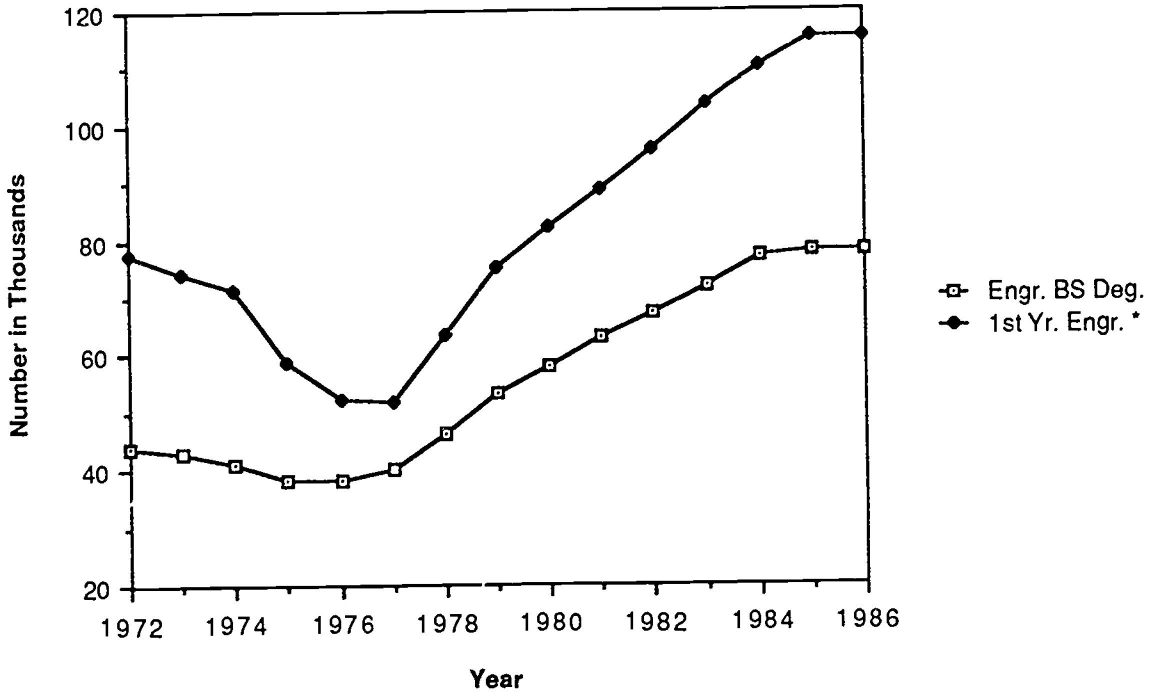
[11] The basis for this assumption is the relatively constant share of bachelor's degrees awarded in the fields of physical sciences, mathematics, and engineering. This share fell between 1972 and 1975 from 10 percent to 8 percent. It remained at 8 percent in 1976 and 1977 and rose from 8 percent to 12 percent between 1978 and 1982. The positive correlation over this period between this share and the share of degrees awarded in engineering fields indicates that variations in engineering degree production did not occur entirely at the expense of degrees in closely related fields. See National Science Foundation, *The Science and Engineering Pipeline* (PRA Report 87-2), Washington, D.C.: NSF, April 1987.

[12] Given past relationships between engineering freshman enrollment and the number of engineering bachelor's degrees granted 4 years later, the projected decline in bachelor's degree production can be expected to be less dramatic than the 4 percent average annual rate of decline in enrollment experienced since 1982.

[13] The GRE scores are for the quantitative reasoning portion of the test and include test-takers planning to pursue further study in engineering.



* Enrollment 4 years earlier.
NOTES: See Appendix Table 3, page 46.

Figure 6. Engineering enrollments and bachelor's degrees, 1972-1986.

TABLE 1: High School Grade-Point Averages, Mean Scholastic Aptitude Test (SAT) Scores, and Mean Graduate Records Examination (GRE) Scores for Engineering Students, Selected Years, 1972-1986

Year	Percentage with A or B Averages	Mean SAT Scores		Mean GRE Scores on Engineering Subject Test
		Verbal	Quantitative	
1971-72	61.7	*	*	*
1974-75	63.6	*	*	583**
1977-79	69.8	448	540	594
1980-81	66.6	446	534	590
1982-83	64.8	448	539	599
1983-84	63.8	453	543	604
1984-85	65.2	453	545	615
1985-86	65.6	*	*	616

* Data are not available.
**Data are for the year 1976.
SOURCES: Cooperative Institutional Research Program, *The American Freshman: Twenty Year Trends*, Los Angeles: Higher Education Research Institute, Graduate School of Education, University of California, January 1987; Educational Testing Service.

TABLE 2: Job Openings and Source of Supply To Fill Them, 1972-1986 and 1984-1986 (annual averages)

Year	Number of Job Openings (thousands)	
	Low Estimate	High Estimate
1972-1986		
Total openings	125	185
Growth	95	95
Replacement	30	90
Total hires	125	185
New degrees	60	88
Other sources	65	97
1984-1986		
Total openings	131	203
Growth	90	90
Replacement	41	113
Total hires	131	203
New degrees	78	119
Other sources	53	84

neering degrees, technicians, or immigrant engineers). Another implication emerging from this analysis is that degree production seemed to have responded to employment changes, but with a lag. Degree production reversed its downward trend in 1976 and began to grow rapidly after 1978. As result, the gap between the range of job openings estimated by the Committee and degree production began to narrow in the late 1970s and early 1980s. A significant amount of this growth in engineering degree production can be attributed to nondemographic factors.

Other Sources of Supply

Nontraditional sources of supply (sources other than new U.S. degree recipients in engineering) were used to fill job openings in engineering not filled by new degree holders (Table 2).

Field Mobility. The major nontraditional source of supply is occupational mobility. Individuals with degrees in closely related fields are recruited to fill job openings. Management typically supplies a significant amount—almost 60 percent of the inflow from other fields between 1972 and 1978.[14] Also, most of the movement out of engineer-

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[14] The sources for this data are unpublished OSEP tabulations and the National Science Foundation's *Study of Occupational Mobility of Scientists and Engineers* (NSF 80-317), Washington, D.C.: U.S. Government Printing Office, 1980.

ing is to management. This large amount of reciprocal flow suggests that:

(1) Firms may use managerial or other positions as buffer stocks in which they store valuable human engineering resources during slack times and from which they draw down these resources during periods of strong demand; or

(2) Respondents to the NSF surveys from which these data were compiled are ambivalent about how to classify themselves occupationally, perhaps because they have both field-specific and management functions, and are therefore inconsistent in their responses to this question; or

(3) For some unknown reason (perhaps the status of engineering may have risen relative to the status of management) individuals self-identifying their occupations may have had an increasing bias toward self-identifying engineering during this period.

In addition, there is a large amount of reciprocal flow between engineering and computer specialties. Almost one-half of the inflow to computer specialties from other occupations came from engineering and about one-tenth of the inflow to engineering from other occupations came from computer specialties.[15]

A consequence of this type of mobility is that a significant portion of the engineering work force has degrees in nonengineering fields. A further consequence of continued reliance on this source of supply increasingly in a period of growing demand would be that the proportion of employed engineers with degrees in nonengineering fields might be expected to increase. The Committee examined NSF data for 1972 and 1982, years for which reasonably comparable data were available: the proportion rose from roughly 15 percent in 1972 to approximately 20 percent in 1982 (Figure 7).

The data on computer specialties are particularly suspect. During this period computer science gradually became a discipline in its own right (frequently, but not universally, associated with engineering). At the same time, "computer specialties" includes many computer practitioners (e.g., programmers and systems analysts) who are, in the opinion of many, not appropriately associated with engineering at all--

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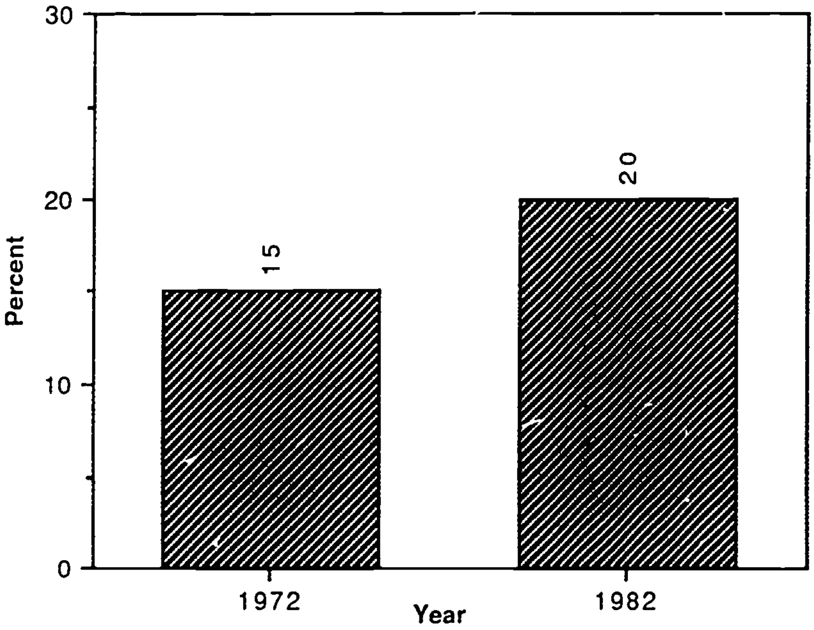
[14] The sources for this data are unpublished OSEP tabulations and the National Science Foundation's *Study of Occupational Mobility of Scientists and Engineers* (NSF 80-317), Washington, D.C.: U.S. Government Printing Office, 1980.

[15] The source of these data is unpublished OSEP tabulations of NSF's experienced sample files.



SOURCE: Unpublished tabulations from NSF's Surveys of Experienced Scientists and Engineers.

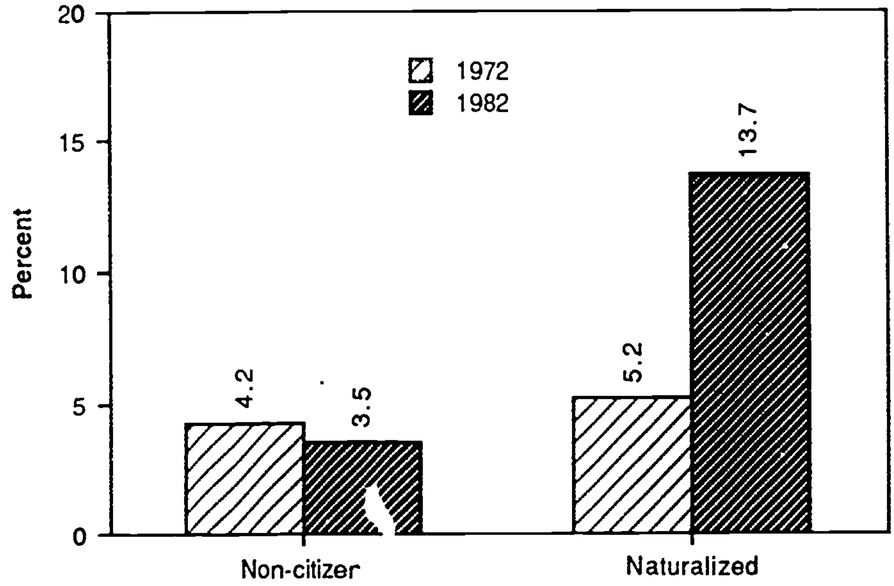
Figure 7. Percentage of the engineering work force with degrees in nonengineering fields, 1972 and 1982.

perhaps more properly associated with engineering technicians or vocational technicians.

Immigration/Foreign-Born Engineers. A second important nontraditional source of supply is foreign-born engineers. Some of these are educated abroad and recruited to work here, while others—particularly at the doctorate level—are educated in American institutions and either remain in this country after they complete their degrees or return to the United States after an absence required by immigracion laws.

The percentage of the engineering work force that is foreign-born rose from about 9 percent in 1972 to over 17 percent in 1982 (Figure 8). It is interesting to note that, while the percentage of foreign-born engineers increased during that period, the percentage who are noncitizens remained essentially unchanged. The entire increase in the percentage of the engineering work force that is foreign-born is the result of an increase in the percentage of the engineering work force that is composed of naturalized citizens.

The foreign-born engineers are heavily concentrated among engineering doctorates. The percentage of engineering doctorates who are foreign-born is almost double the comparable percentage for engineering



SOURCE: Special tabulations from Oak Ridge Associated Universities, based on the National Science Foundation's 1972 and 1982 Postcensal Surveys.

Figure 8. Distribution of the foreign-born engineering labor force by citizenship status, 1972 and 1982.

baccalaureates.[16] Since academe is an important employer of engineering doctorates (roughly one-third are employed in academic institutions), it is not surprising to find that foreign-born engineers comprise a substantial share of this country's engineering faculty.[17]

Nondegreed Engineers. Another prominent nontraditional source of supply for engineers is the pool of nondegreed technicians who are promoted to engineering activity on the basis of their experience. Typically, these individuals are assigned engineering functions that re-

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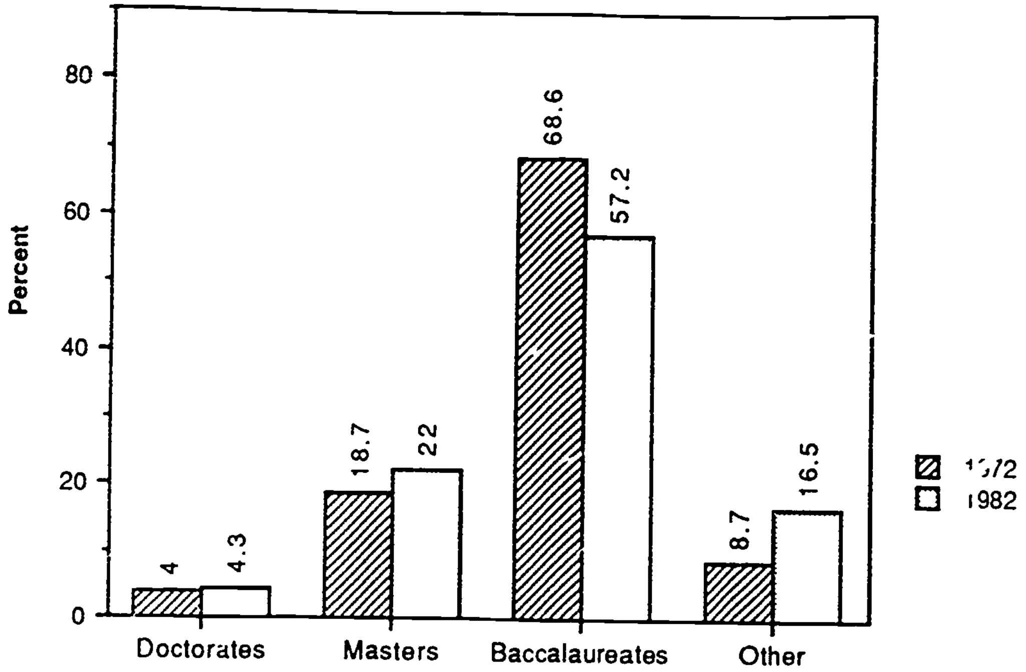
[16] In 1982, noncitizens and naturalized citizens accounted for 15 percent of baccalaureates, 22 percent of master's degrees, and 36 percent of doctorates in the engineering labor force. See also the Committee on the International Exchange and Movement of Engineers, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues,* Washington, D.C.: National Academy Press, 1988.

[17] Based on comments from an engineering dean, anecdotal evidence suggests that some western European countries may be having similar experiences.



SOURCE: Unpublished tabulations from NSF's Surveys of Experienced Scientists and Engineers.

Figure 9. Distribution of engineers, by degree level, 1972 and 1982.

quire less sophisticated technical backgrounds and are not strong candidates to move ultimately into managerial positions.

The Committee did not have information on the number of engineers who did not have a degree. Instead, it used a proxy based on NSF data --the number of engineers who reported degree levels other than the traditional bachelor's, master's, or doctorate degrees.[18] The percentage of engineers in this degree category rose between 1972 and 1982 from 8.7 percent to 16.5 percent (Figure 9). Roughly three-quarters of these engineers--77 percent in 1972 and 73 percent in 1982--were employed in industry. Because this proxy includes engineers other than those with no degree, however, the Committee can not necessarily conclude that a larger number of engineering job vacancies were filled by nondegreed workers as a nontraditional source of supply.

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[18] Although this proxy includes those with no degrees at the bachelor's level or above, it also includes individual engineers whose degrees could not be readily classified. The latter set of engineers consists largely of foreign engineers with degrees from foreign institutions. It is noteworthy, although perhaps coincidence, that the number of "other" degrees closely approximates the number of foreign-born engineers.

Salaries of Engineers

As noted earlier, employment of engineers has increased dramatically since 1972, rising at an average rate of almost 7 percent per year. In the absence of comparable increases in the supply of engineers, the relative salary of engineers should have increased. The Committee examined several series describing trends in engineering salaries to determine the extent to which salary adjustments were necessary to accommodate this employment increase: (a) salary data by years since receipt of the baccalaureate compiled by the Engineering Manpower Commission from its annual survey of employers and (b) income of engineers compiled by the Bureau of the Census from its Current Population Survey. From the former series, salaries of engineers who were 0, 6, 15, and 25 years from the receipt of the baccalaureates were examined.

In each of the series, engineers' salaries were found to increase by more than 100 percent between 1972 and 1986, and in some cases these salaries increased by almost 200 percent (Table 3). When these salaries are deflated by the Consumer Price Index to express them in real terms (i.e., in terms of dollars of constant purchasing power), this strong upward trend is virtually eliminated (Figure 10). A slight downward trend is observed in the 1970s for the more experienced engineers in the Engineering Manpower Commission data, and a slight upward trend is observed over the entire period in the salary data compiled by the Bureau of the Census.

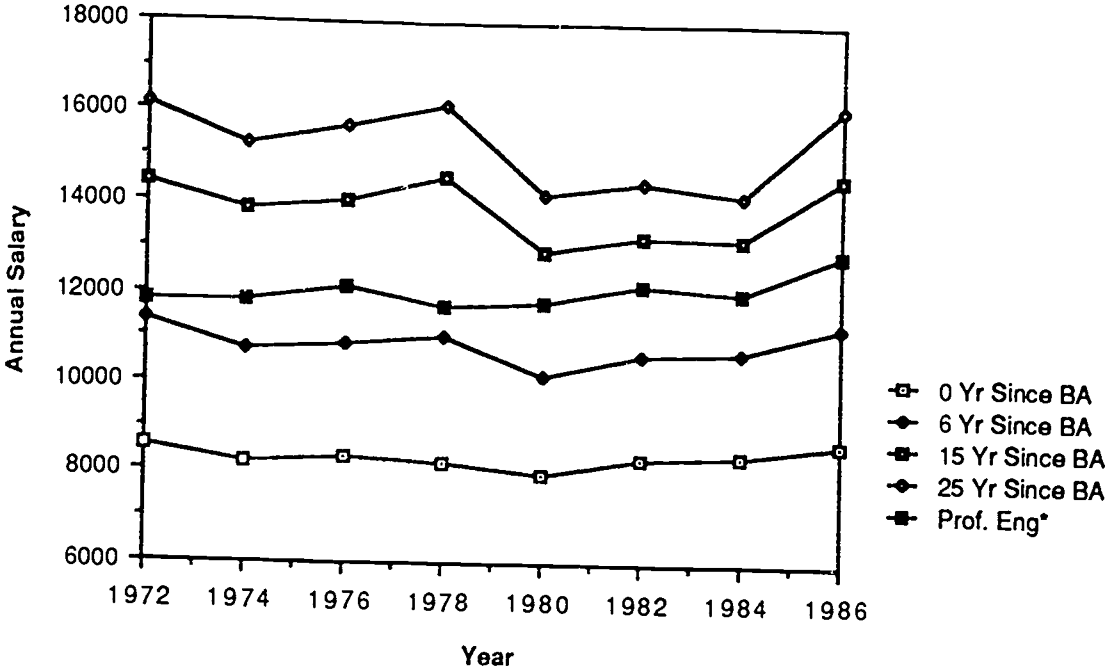
A similar finding is observed when the salary data are deflated by wage and income series for the general work force to derive indicators of relative salaries (see Appendix Tables 4-7). When deflated by the

TABLE 3: Salaries for Engineers, 1972-1986

	Number of Years Since B.S. Degree Obtained				Median Total
Year	0	6	15	25	Annual Income*
1972	$10,700	$14,250	$18,050	$20,200	$18,210
1974	12,150	15,800	20,400	22,500	20,660
1976	14,250	18,450	23,900	26,700	23,700
1978	16,050	21,500	28,350	31,500	26,780
1980	19,600	25,150	28,350	31,500	31,874
1982	24,100	30,800	38,417	41,900	39,000
1984	26,100	33,300	41,050	44,200	43,017
1986	28,600	37,200	47,917	52,950	47,200

*For years 1972-1980 salary information was unavailable; salaries listed are for 1971-1979.

SOURCES: Engineering Manpower Commission, *Engineers' Salaries*, Special Industry Report, 1986; National Society of Professional Engineers.



NOTE: Salary data were deflated by consumer price index 1967 = 100. See Appendix Table 3, page 46.

Figure 10. Engineers' salaries (in 1967 dollars).

earnings of production workers in private nonagricultural industries, the salaries of engineers display an upward drift, increasing between 1972 and 1986 by 10 to 20 percent. When deflated by the incomes of professional and technical workers, the upward drift becomes less dramatic in one case and becomes a slight downward drift in the other. Relative salaries increase by 2 to 5 percent using the data compiled by the Engineering Manpower Commission, and relative salaries decrease by about 4 percent using the data compiled by the Bureau of the Census.[19]

Based on its analysis of real and relative engineering salaries, the Committee finds relatively little variation. This suggests two conclusions. First, the long-run supply of engineering talent appears to be highly responsive to salary variation. (In the jargon of the economist, the elasticity of supply of engineering talent with respect to salaries is quite large.) This responsiveness operates through the traditional and nontraditional sources of supply discussed earlier in this chapter. Second, as a result of supply growing to meet demand,

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[19] The trend data derived from the incomes of professional and technical workers should be treated with caution, however, since the definition of professional/technical workers was altered in 1982, introducing an element of noncomparability into that particular time-series data base.

engineering inputs do not appear to have become more expensive--either in real or in relative terms--as a result of the dramatic increases in employment that have been experienced since 1972.

Future Supply and Demand

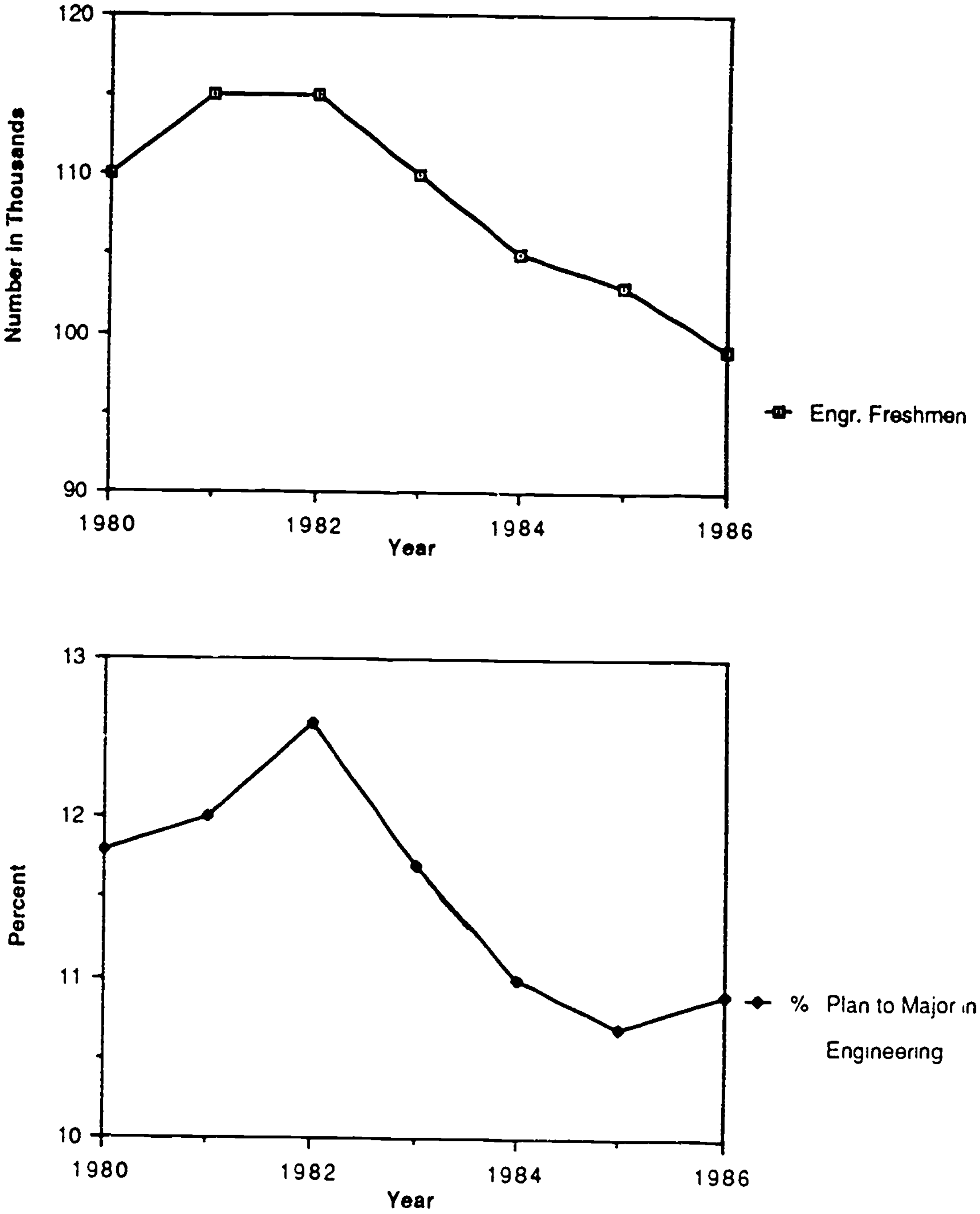
The marked changes in demographic trends and the significant changes in utilization that are emerging in response to the need to improve our competitive position in an increasingly global economy make the findings for the 1972-1986 period of growth difficult to extrapolate to the next 15 years. The period to 1980 was characterized by an increasing population of college-aged youth who enlarged the pool from which new engineering graduates could be drawn. This favorable demographic trend has been enhanced by an increasing fraction of the undergraduate student body choosing engineering as a major: the larger fraction who opted for careers in engineering is consistent with a shift in attitude that made technologically oriented activity less socially stigmatized than it had been during the late 1960s and early 1970s. The next 15 years will be characterized by a pool that will first decline into the 1990s and then grow less dramatically as we enter the 21st century. In addition, the pressure to remain competitive in a global economy has caused many industrial firms, in looking for more productive ways to utilize their work forces, to downsize them. The Committee believes that the smaller work force remaining has a higher proportion of engineers who utilize their engineering skills not only in primary engineering activities, but also increasingly in such activities as production and sales.

Supply

Production of new engineering baccalaureates is expected to have peaked in 1986. Freshman engineering enrollments have been falling since 1982, and a smaller percentage of the entering freshman class has been reporting interest in majoring in engineering (Figure 11). Based on current trends in engineering freshman enrollments, the number of bachelor's degrees produced in the year 1990 is expected to decline 16 percent to about the 1983 levels.

Whether the downward trend will be reversed beyond 1990 will depend on future trends in freshman enrollment. This enrollment is generally sensitive to perceived employment opportunities and business conditions. A frequently used indicator of these opportunities--the High Technology Recruiting Index--has shown significant strength recently after 3 years of relative weakness. If this rejuvenation in industrial job opportunities turns out to be a permanent reversal in trends, the Committee would consider it as evidence to support an optimistic outlook for future freshman enrollment.

Another important factor in projecting future supply is the ethnic



SOURCE: Cooperative Institutional Research Program, *The American Freshman: Twenty Year Trends*, Los Angeles: Higher Education Research Institute, Graduate School of Education, University of California, January 1987.

Figure 11. Current trends in engineering freshman enrollment and in the percentage of all college freshmen who plan to major in engineering, 1980-1986.

composition of the 18- to 21-year-old population. That cohort will increasingly consist of minority groups that have not tended to go into engineering studies. For example, although blacks constitute 10 percent of total U.S. employment and 6 percent of the professional and technical work force, they represent only 1.7 percent of the engineering work force. In addition, although marked advances have occurred in the participation of women in engineering careers, they remain significantly underrepresented, and their enrollment in engineering programs has been declining. Since the supply may be insufficient relative to the demand, it is very important that positive steps be taken to interest increasing numbers of both minorities and women in engineering careers and that they be provided support requisite to their completing the degree programs.

Demand

The number of job openings arising from attrition is expected to increase over the next 15 years because of the increased number of engineers approaching retirement age. Almost 20 percent (about 400,000) were over 50 years of age in 1982, compared with almost 10 percent (90,000) in 1972. The effect of these anticipated retirements may be partially postponed, however, by the impact of the recently passed congressional bill abolishing mandatory retirement for most occupations and by other factors such as the improved health and longevity of our population. In addition, any severe economic downturn would encourage many individuals to continue working beyond retirement age considered normal during the past 15 years.

The Bureau of Labor Statistics (BLS) projects a 2 percent annual rate of growth in engineering employment between now and the year 2000.[20] However, several factors—the recent downsizing of technical work forces by a significant number of large firms in response to competitive pressures and technological developments in the areas of expert systems and computer-assisted engineering—may operate to damp employment growth rates. (These offsets may already be factored into the BLS projections. Annual growth rates generated from these projections are well below the rates reported earlier in this chapter for the 1972-1986 period.) On balance, however, unless radical shocks occur to the U.S. economy, engineering employment growth can be expected to continue to generate additional new job openings at a modest rate beyond replacement demand.

Given the experience of the last 15 years and expectations for the next 15 years, the Committee concludes that the need for engineers can not be met entirely by reliance on traditional sources of supply. The

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[20] See George T. Silvestri and John M. Lukasiewicz, Projections 2000: A look at occupational employment trends to the year 2000, *Monthly Labor Review*, September 1937, pp. 46-63.

shortfall may be made up by relying in part on nontraditional sources and in part by a more effective utilization of the experienced engineering talent pool. (It should be noted that this conclusion is not unique to engineering. The same demographic factors apply to all occupations at all skill levels.)

III. QUALITY IMPLICATIONS

1972-1986 Engineering Labor-Market Experience

The material presented in Chapter II revealed that the period 1972-1986 was one of significant growth in the employment of engineers. It also revealed that, although degree production also increased dramatically, the increases occurred with a lag and were insufficient to fill the number of engineering job openings generated during that period.

Several consequences flow from these findings. First, the failure to realize a level of degree production that would be adequate to fill all job openings meant that, in part, employers met their engineering employment needs by relying on other, nontraditional[21] sources of supply--by recruiting from other fields, by hiring foreign-born engineers, and by upgrading technicians--and by recruiting more strongly from groups traditionally underrepresented in engineering careers. There is concern that continued reliance on some of these nontraditional sources could affect the "quality" of the engineering work force.

There is also concern that satisfying the need for engineers by utilizing degreed individuals from other fields draws human resources away from them--particularly the closely related fields of physics, chemistry, and mathematics--and that a continual drawing down of these talent pools could ultimately cause significant damage to the vitality of these fields.

Based on the material cited previously, the Committee also found that notable differences existed between industry and academe in the way in which they utilized nontraditional sources to meet their employment needs. Industry, which employs predominantly baccalaureates in engineering work, tended to recruit from a variety of nontraditional supply sources--individuals holding degrees in closely related fields, technicians, and foreign-born engineers--as well as from underrepresented groups. Academe, which relies heavily on doctorates to meet its needs, recruited foreign-born engineers.

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[21] Nontraditional sources of engineering supply have included individuals with nonengineering degrees, technicians, and immigrant engineers.

Effects of 1972-1986 Experience on the Quality of the Engineering Work Force

The Committee, through the commissioned papers and the workshop held to review and discuss them, investigated the effects on the quality of the engineering work force that resulted from reliance on nontraditional sources of supply over the past 15 years. It found that representatives from industry perceived no change in the quality of their work forces. It should be noted, however, that the Committee received feedback only from representatives of very large firms; since small firms constitute a substantial part of the entrepreneurial activity of the nation in the area of technology, the lack of information on how well small firms are meeting their needs for engineers constitutes an important gap in our knowledge base. This is especially important since small firms are believed to constitute a major source of new job creation in the United States.

Some individuals expressed concerns, however, that increased reliance in academe on foreign-born faculty and teaching assistants (TAs) could have deleterious effects on the quality of teaching in engineering programs. This concern relates most often to the linguistic ability of these individuals in transmitting educational concepts in English. In addition, the attitudes of faculty and TAs from some foreign countries are alleged by one participant at the Committee-sponsored workshop to discourage some women and members of some ethnic minority groups from pursuing further engineering study. Furthermore, foreign-born faculty and teaching assistants on U.S. engineering campuses may have important influences on student attitudes among the engineering student body who terminate their educations at the bachelor's degree level and enter industry. It is alleged that these faculty may convey the idea that activities such as production and quality control, which are "hands-on" in nature, are inferior to the seemingly more glamourous and intellectually stimulating research and development (R&D) activity.[22]

Nonetheless, there appeared to be little concern about the effect of increasing reliance on foreign-born faculty and graduate students on the quality of research produced. In fact, it is possible that these highly selected and highly motivated individuals may be intellectually superior (on average) to American graduates willing to work in academe. The Committee has no evidence that the increased use of foreign-born individuals on engineering school faculty has decreased the quality of the product.

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[22] Committee on the International Exchange and Movement of Engineers (CIEME), National Research Council, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues*, Washington, D.C.: National Academy Press, 1987.

Some concern was also expressed that many foreign-born engineers may not be familiar with the U.S. industrial complex and that many are blocked by security regulations from participating in joint programs in many federal laboratories and with defense-related industrial companies. Linkages between academe and nonacademic sectors (i.e., government and industry) may therefore be more difficult to accomplish and somewhat less effective.[23]

Implications of Future Labor-Market Conditions for Quality

Since there will be a continuing need to use nontraditional sources to meet future demands for engineers, the question remains: Will this result in a significant deterioration in the quality of the engineering work force and, if so, will this tend to undermine our international competitiveness?

As noted earlier, the Committee chose to address the quality issue in a particular context--that of competitiveness. Relative prices, production costs, and quality of the product are key ingredients in determining competitiveness. These ingredients, in turn, can be affected by changes in technology and productivity. Engineering labor, as one of many inputs to the production process and the process of creating changes in technology and productivity, can therefore have an impact on competitiveness. Accordingly, the Committee approached the quality issue in terms of the relative cost-effectiveness of filling engineering positions with workers having alternative bundles of skills.

One can argue that, in the face of transitory periods of high demand for (or low supply of) college-trained engineers, the brief use of nontraditional sources of supply might not harm the quality of the product being produced nor reduce its competitiveness in international markets. On the other hand, if the demand is persistently high (and/or the supply of college-trained engineers is persistently low), the cumulative costs associated with the continuing need to rely on these sources of supply might result in an increase in the price of the product, a decrease in its quality, and (in either case) a reduction in the international competitiveness of its producer.

Adjustment Mechanisms: Assessing Their Impact on Quality

Given existing inadequacies in the ability of employers to fore-

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[23] See F. Karl Willenbrock, "Performance of Engineering Faculty in the United States," in Appendix D of this report and the CIEME report cited earlier.

cast future labor-market conditions accurately, their decision making occurs in a world of substantial uncertainty. Employers use a variety of mechanisms to cope with this uncertainty.[24] As noted in the commissioned papers (see Appendix D), a large number of possible adjustments may be made when demand exceeds supply. When traditional sources of engineering supply are perceived by employers to be growing scarce, they adopt the following types of temporary adjustment mechanisms: (1) utilize the existing engineering work force more intensively; (2) hire degree recipients in closely related fields to work as engineers, (3) hire foreign-born engineers; (4) hire or upgrade technicians; (5) discourage engineers from taking managerial or nonengineering positions; and (6) discourage retirement. The distinguishing feature of these mechanisms is that they can be undertaken without raising wage rates (increased wages can be both costly and permanent).

Employers also have options for adapting to situations that they perceive to be of longer duration. One is to increase the productivity of the existing engineering work force by using additional units of other (nonengineering) inputs (such as capital and other types of labor) or by contracting out engineering services in the United States or abroad. Another is to increase wage rates, making careers in engineering appear more attractive (thereby tending to increase the long-run supply of engineers--those newly graduating from colleges and universities) and providing incentives to employers to economize on the more costly engineering work force.

Each of these coping mechanisms involves some additional costs. The fundamental real issues are whether the incremental costs are transitory or permanent and whether they are offset by comparable increases in engineering productivity. If the cost increases are permanent and are not offset by increases in engineering productivity, then they may affect either product prices or profit margins. In either case, competitiveness could be affected in the long run. The permanence of the cost increases associated with increases in engineering demand will depend in part on the speed with which engineering degree production adjusts to the perceived increase in demand and in salary. Given the approach to quality adopted by the Committee, the impact that these measures may have on quality will depend critically on whether the productivity increases associated with these measures will exceed the incremental costs: if they do, one will be able to conclude that the quality of the engineering work force has been enhanced; if they do not, then, depending on the relationship between these productivity and cost increases, one will be able to conclude that quality has either remained unchanged or deteriorated.

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[24] Committee on the Education and Utilization of the Engineer, Commission on Engineering and Technical Systems, National Research Council, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* Washington, D.C.: National Academy Press, 1985.

This wide array of possible adjustments and their associated productivity and cost implications greatly complicates the task of assessing quality. However, viewing the impact of these mechanisms in terms of these variables helps to clarify the interpretation of quality indicators that might be appropriate. For example, if we use the amount of formal schooling possessed by workers as a measure of quality, then any adjustment that requires hiring "less qualified" (less educated) workers might be considered a decline in quality. However, the costs to society of the formal education of these workers is lower, and, with appropriate training, either on the job or in a more formal program, they could be as productive as their more educated colleagues. Using the productivity and cost criteria discussed earlier, these less educated workers might produce engineering work of equal quality.[25] A fortiori, if they were to cost less (such as instances in which they command lower salaries), these less educated engineers might represent even better quality than their more educated colleagues. Another aspect of the effect of education is the effect of overeducation. Research on the effect of education for the total (i.e., engineering and nonengineering) work force found that "too much" education produces job dissatisfaction.[26] In engineering, this could be manifest by using degreed engineers to perform technician-level work. This effect would be an indicator of quality deterioration if job dissatisfaction were associated with lower performance or productivity.

Thus, the quality of the engineer is a complex concept that must be evaluated in terms of both the productivity of the engineer and the cost of filling engineering positions with workers providing that amount of productivity. The productivity of the engineer, in turn, reflects both the skills embodied in the workers filling engineering positions, the skills required by those positions, and the ingenuity with which management utilizes these workers to fill their requirements.[27]

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[25] This would be so if any productivity differences between engineers with differing amounts of education were also accompanied by wage or other cost differentials of equal magnitude.

[26] See, for example, Robert Quinn and Martha Baldi Mandilovitch, *Education and Job Satisfaction: A Questionable Payoff,* Ann Arbor: University of Michigan Survey Research Center, 1975; Anne Kalleberg and Aage Sorensen, "The Measurement of the Effects of Overtraining on Job Attitudes," *Sociological Methods and Research* 2(2):215-238, November 1983; and Mun Tsang, *The Impact of Overeducation on Productivity: A Case Study of a Communication Industry,* unpublished doctoral dissertation, Stanford University.

[27] See Robert McGinnis, "Interactions Between Labor-Market Adjustments and the Quality of Performance in Engineering: A Sociological Perspective," and Alan L. Porter, "Changes in Engineering Quality and Performance: Potential Indicators of Adjustment," in Appendix D of this report.

To evaluate this engineering productivity, one must be able to specify and observe the output of engineers. This proves to be a difficult undertaking. Alternatively, one can observe the consequences of this output (e.g., through indicators of technological change and innovation, such as patents, or through indicators of improved efficiency, such as increased profitability, improvement in product quality, or increased market share). The difficulty with this approach is that these consequences reflect the influence of a large number of factors, of which engineering productivity is only one. Thus, it is difficult to isolate the unique effect of the engineering input. Another possible indicator of the quality of engineers is the performance ratings of supervisors. This indicator has several major drawbacks. First, it cannot be used for comparisons among engineers rated by different supervisors, since the standards of performance used by these supervisors are not necessarily the same. Second, since the ratings are generally relative (rather than absolute) rankings of engineers, one can not use them to determine whether quality has changed over time.[28]

The task is made even more difficult by the current environment in which the skills that employers require from their engineering forces are changing dramatically. These skills are changing in response to a variety of factors, many of them motivated by the need for the United States to improve its industrial competitiveness. This need has resulted in downsizing of work forces and a gradual shift into production of high value-added, customized products, with associated emphasis on the ultimate user and on both product and process improvements. This new emphasis requires engineers to pay more attention to factors such as marketability and producibility and to give less weight to elegance and style in designing the product. Another result of this shift in emphasis is the need for interaction among a wider range of engineers and nonengineers.

Changing technologies also change skill requirements. Process and organizational innovations--such as computer-aided design, computer-assisted manufacturing, expert systems, and group technology--are reducing the amount of time and effort required in the design/development/production cycle and are broadening the nature of the engineering function.[29] The effectiveness with which these innovations can be integrated into the work force depends in part on the match between the skills of the work force and the changes that are being introduced. Un-

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[28] It is possible, for example, to have a case in which the average supervisor ranking remains unchanged while the average quality of the engineers being rated either increases or decreases.

[29] See Gerald I. Susman, "The Impact of Advanced Manufacturing Technology on the Effective Utilization of Engineers," in Appendix D of this report.

derestimating these skill requirements can result in failure.[30] Some suggest that industrial competitiveness would be well served by moving more technically trained people into management positions. In addition, there is a growing interest on the part of industrial management in assigning direct production responsibilities to more engineers. Such shifts in roles suggest a further broadening of engineering functions.

In this context of rapid change, maintaining engineering talents at the state of the art is increasingly difficult. A growing gap in technical knowledge emerges as the state of the art pushes forward. This gap can be narrowed or eliminated through the provision of continuing education for the experienced engineering work force. The importance of such training is illustrated in a recent comparative study of productivity growth that concludes that inadequacies in the training of skilled workers is a major source of the weakness of Britain (relative to West Germany and the United States) in products requiring relatively large amounts of engineering and technical skill.[31] Unfortunately, little hard information exists to assess the magnitude or the impact of such training or to know how rapidly technical education becomes obsolete.

Current Practices:
Implications for the Future

The indicators examined in this study were limited to those embodied in workers and characterized by their ability to be observed and quantified--degree level, degree field, years of experience, citizenship status. Obviously, a large number of factors other than these observable characteristics impact on engineering productivity. Many of these are discussed in the background papers commissioned by the Committee (see Appendix D)--motivation, the ability to interact with non-engineers, flexibility, intelligence, and so forth.

Given the paucity of data and the exploratory nature of this study, the Committee relied heavily on the experience and judgment of practitioners in evaluating the implications of the various adjustment

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[30] See, for example, Richard Kazis, *The Relationship Between Education and Productivity: Implications for the Competitiveness of American Manufacturing and the Movement for Educational Reform*, unpublished paper, January 1988; Hal Salzman and Philip Mirvis, "The Workforce Transition to New Technologies: Changes in Skills and Quality of Work Life," *Western Economic Review* 4(2): July 1985; and Jack Brizius and Susan Foster, *Enhancing Adult Literacy: A Policy Guide*, Washington, D.C.: Council of State Policy and Planning Agencies, 1987, for discussion of cases involving the general work force.

[31] S. J. Prais, *Productivity and Industrial Structure*, Cambridge, Cambridge University Press, 1981, cited in Kazis, *op. cit.*, p. 36.

mechanisms for quality. Moreover, given the wide variety of functions and activities in which engineers are engaged, the Committee decided to explore the issue for three distinct types of engineer: (1) the academic engineer; (2) the industrial R&D engineer; and (3) the industrial non-R&D engineer. The latter type of engineer is the largest component of the engineering work force (almost 60 percent of the engineering work force reported activities other than R&D or R&D management as their primary work involvement in 1984). The engineering work force is still quite heterogeneous even after this distinction is made.

Academic Engineers (Engineering Faculty Members). As noted earlier, adjustments in this particular labor market have been limited primarily to increased hiring of foreign-born faculty. This suggests that the skill needs of academe are quite specific and can not, in large part, be met by the upgrading of individuals not educated in engineering fields. However, hiring from closely related fields can be an effective adjustment mechanism, resulting in cross-utilization and more openness to new ideas (it must be noted, however, that such a practice might only reallocate the problem of insufficient numbers of faculty to other fields). A marked difference among institutions was noted in their ability to recruit American doctorates. High-prestige schools with major externally-funded research programs are in a stronger competitive position.

Undergraduate enrollments in engineering programs have leveled off recently, but a significant need still exists for new faculty (1) to fill existing vacancies and (2) to replace existing engineering faculty who are expected to retire over the next 15 years. In addition, should there be renewed growth in undergraduate enrollments as expected in the late 1990s, there will also be a need for new faculty to fill the additional instructional slots that will be created by this growth. Although retirees can help to close the gap temporarily, the Committee concludes that recruitment of foreign-born engineering faculty to meet these needs will continue. The Committee also believes, however, that while the use of these foreign-born engineers may produce some problems with respect to some aspects of engineering education, it is a manifestation of an even deeper problem: the unwillingness of native-born American engineering students to pursue careers requiring doctorate degrees in engineering and to undertake academic careers. Given the political uncertainties that exist with respect to international relationships, the Committee believes it would be undesirable to rely excessively on foreign sources of supply to meet our engineering needs. The solution to this problem lies in encouraging our native-born engineering students, particularly women and members of minority groups traditionally underrepresented in engineering, to pursue such careers and in actively recruiting high-quality individuals to faculty positions. Limiting the number of foreign-born engineers on our campuses, however, is not desirable; we need them, too. It is especially important that renewed efforts be made to recruit minorities and women, both representing huge, as yet not fully tapped, resources with current low participation in engineering.

R&D Engineers in Industry. Adjustment mechanisms for this group of engineers include increasing pay and more intensive use of other mechanisms to recruit staff with engineering degrees. When these mechanisms prove to be temporarily inadequate, employers resort to recruitment from closely related technical disciplines, upgrading of qualified technicians (particularly to fill positions requiring lower-level engineering skills), utilization of retirees, and recruitment of immigrant engineers.[32] Other options, such as cross-training of workers with degrees in nontechnical fields or reassignment of workers from non-R&D functions, are considered less viable.[33] Indeed, there were expressed beliefs that technicians are limited in their potential career development and that foreign-born engineers are difficult to use in work requiring security clearances. There is also evidence of increasing contract engineering work off-shore.

The variety of mechanisms used by employers of R&D engineers suggests that a flexibility in the nature of the skill requirements for R&D engineers tends to minimize quality problems arising from their use. Based on the limited amount of evidence gleaned from the experience and judgment of practitioners in large R&D-intensive enterprises, there is no reason to expect significant quality deterioration from the temporary use of mechanisms such as those outlined above. Some of the practitioners also indicated that they are generally able to recruit an adequate number of highly qualified R&D engineers by maintaining competitive salary scales. The reader is cautioned, however, that these conclusions may be limited to very large, R&D-intensive firms.

Non-R&D Engineers in Industry. The evidence compiled by the Committee supports the view that 30 to 80 percent of the new engineers

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[32] See Russell G. Meyerand, Jr., James R. Bogard, and Stanley A. Brodtman, "Assessment of Hiring and Performance of Scientists and Engineers Engaged in Industry R&D Activities," in Appendix D of this report.

[33] For evidence supporting this judgment, see Robert Quinn and Martha Baldi Mandilovitch, *Education and Job Satisfaction: A Questionable Payoff*, Ann Arbor: University of Michigan Survey Research Center, 1975; Anne Kalleberg and Aage Sorensen, "The Measurement of the Effects of Overtraining on Job Attitudes," *Sociological Methods and Research* 2(2):215-238, November 1983; and Mun Tsang, *The Impact of Overeducation on Productivity: A Case Study of a Communication Industry*, unpublished doctoral dissertation, Stanford University.

hired by large industrial firms are assigned to non-R&D activity.[34] The reason given for placing engineers in these positions is that their training enables them to perform better or achieve results sooner. These engineers, however, are likely to cost more because they generally command higher salaries than comparable nonengineers.[35] Also, productivity may be lower if they feel that they are being underutilized. Thus, using the criteria of costs and productivity discussed earlier, it is not obvious, a priori, that engineers who are employed in non-R&D jobs will be superior in productivity per unit cost to nonengineers in these jobs. The fact that management uses this mechanism so frequently, however, is strong circumstantial evidence that the quality of the output is considered worth its cost.

A Final Word

The Committee was limited by available information to consideration of the quality implications of changes in the observable characteristics of the engineering work force. It recognizes, however, that there is a serious deficiency in our ability to assess the impact of both quantifiable and nonquantifiable skills and to evaluate the influence of the work environment on engineering productivity. A number of suggestions emerged from the commissioned papers for modest pilot studies to investigate the feasibility of deriving indicators of engineering productivity and measures of skill and work-environment determinants from industry case studies and from cross-national comparisons. A considerable amount of fundamental research will be necessary before credible indicators of engineering productivity will be available and before the determinants of engineering productivity are better known and their impacts more fully understood.

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[34] See James F. Lardner, "Performance of Scientists and Engineers in Non-R&D Industries," in Appendix D of this report. This finding is based on the responses of senior executives in a small sample of large industrial firms contacted by the Committee as part of this study: three machinery manufacturers, two electronics manufacturers, an aerospace firm, and a manufacturing and engineering firm.

[35] Some evidence to support this judgment may be gleaned from salaries for M.B.A.s; on average, those who have technical backgrounds are paid more than those who do not. Similarly, Drs. Robert C. Dauffenbach and Michael G. Finn have analyzed salaries of employed engineers in 1982 and have demonstrated clear salary differentials between engineers with engineering degrees and engineers with nonengineering degrees: those with physical science degrees are paid an average of 4 percent less, for example, and those with business degrees (but doing engineering) average over 5 percent less (unpublished data in letter from Robert C. Dauffenbach to Harrison Shull, February 28, 1988).

IV. CONCLUSIONS AND RECOMMENDATIONS

Given the complexity of the subject under study and the paucity of solid data available to illuminate the key issues involved in assessing the qualitative implications of market responses to increases in the demand for engineers, the report of this Committee should be viewed as a summary of an initial, exploratory effort. Despite these limitations, however, the Committee was able to arrive at a number of conclusions and recommendations based on the empirical evidence available and the experiences and judgments of the practitioners and scholars who were involved in the study.

The Committee reached the following major conclusions:

1. There is no evidence that any perceived decrease in U.S. competitiveness in world markets is attributable to the nonavailability of engineering talent of suitable quality in U.S. industry. There is positive anecdotal evidence that, at least in larger corporations, there has been a sufficient supply of engineering talent of adequate quality.[36]

2. A substantial portion of the job openings for engineers has recently been filled from pools other than the traditional supply source, new U.S.-citizen engineering degree recipients.

3. One significant nontraditional source has been degree recipients from closely related fields—for example, geology, physics, chemistry, mathematics. The siphoning off of these students into engineering may have been partially responsible for the lack of increase in Ph.D. degree production exhibited by these fields in recent years.

4. Another important nontraditional pool used to fill these job openings has been foreign-born engineers. This has

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[36] An extensive review of the literature on education and productivity reaches a similar conclusion. See Richard Kazis, *The Relationship Between Education and Productivity: Implications for the Competitiveness of American Manufacturing and the Movement for Educational Reform*, unpublished paper, January 1988.

been particularly true for job openings in academe, where a growing number of noncitizens who have earned doctorates in engineering from American institutions have been and are being recruited to fill faculty vacancies.

5. New engineering degree production is somewhat responsive to increases in opportunity, particularly at the baccalaurate level. There is, however, a lag in this response occasioned by the time required to complete requirements for the degree. This time lag is even longer at the doctorate level, where it may take 6 or more years to acquire the degree. It is not clear, however, that graduate education responds to the same demand factors that seem to affect baccalaureate production.

6. The response from these various sources of supply has been such that the relatively rapid growth in engineering employment that has occurred since 1972 has been accommodated with relatively little increase in either real or relative salaries of engineers. This suggests that the supply of engineering talent has been highly elastic and capable of adapting to wide swings in employment.

7. The Committee could not assess the impact of recent measures to improve the competitiveness of industrial firms (e.g., downsizing, increased use of computer-related technologies) on the demand for engineers. The Committee believes, however, that these efforts will result in an upgrading and more effective utilization of the existing engineering work force.

8. Looking to the future, the Committee anticipates that, given expected demographic trends, the need to rely on sources other than new U.S. engineering degree recipients will continue. Although automation of engineering activities has raised and is expected to continue to raise the level of productivity of those involved in engineering work and despite the recent efforts of many industrial firms to downsize their work forces in order to maintain or improve their competitive positions, there will still be need to utilize nontraditional sources of engineering work.

9. Practitioners from industry who were consulted by the Committee believed that the need to fill job openings with individuals recruited from nontraditional sources did not result in an immediate reduction in the quality of the engineering work force. Although meeting the need

in this way involved some costs for in-service or career training, the costs were believed to be insignificant. Moreover, these costs may partially be offset by the lower salaries frequently paid to individuals with degrees in other disciplines. The Committee emphasizes, however, that this conclusion is based on impressionistic evidence rather than on hard data.

10. Practitioners from academe consulted by the Committee as part of the study believe that the growing need to fill faculty positions with foreign-born engineers is not a cause for major concern, although concerns were expressed about possible limitations that might exist in the teaching capabilities of some because of language difficulties or cultural attitudes. By and large, these new faculty members are strong in their research capabilities. Here again, the Committee wishes to emphasize the impressionistic nature of this evidence.

11. The Committee strongly believes that the growing prominence of the foreign-born on our engineering faculties is symptomatic of a more fundamental problem: the apparent unwillingness of American students to choose careers in engineering that require the doctorate.

12. In-service training of engineers recruited from other disciplines and continuing education of career engineers are important to filling jobs effectively. They enable firms to fill these openings with a minimum loss in performance and they expand the available supply by extending the careers of engineers performing state-of-the-art engineering functions. Unfortunately, little hard data exist to document the extent to which these training and education mechanisms are used and their effectiveness in allowing firms to meet their recruitment needs.

Based on its findings and conclusions, the Committee offers the following recommendations:

1. Both the Administration and the Congress should take steps to assure that the recruitment of foreign engineers is not made more difficult than it is now. These engineers are an essential source of supply, especially to academe, and can be expected to continue to be such a source until more American students are persuaded to pursue doctorates in engineering.

2. Steps should be taken to encourage more American students to pursue doctorates in engineering. One promising mechanism for achieving this objective is to in-

crease the number and stipend size of fellowship and assistantship support provided by the federal government and industry. Another is to increase the amount and quality of equipment available on campuses for engineering research. Yet another is to reduce the amount of effort and the range of uncertainty that exist in securing federal research funding. Finally, industry should reinforce the importance of graduate education for U.S. students by providing rewarding job opportunities and careers to engineers having graduate degrees.

3. Steps should be taken to deepen the pool of students with the backgrounds necessary for pursuing careers in either science or engineering. Important mechanisms for achieving this objective include (a) improvement in the amount and quality of science and mathematics education given to students in elementary and high school and (b) encouragement of an increasing number of women and members of underrepresented racial/ethnic minority groups to select engineering as their careers.

4. Federal policy should be conducive to the continued and more extensive use of in-service and continuing career training by industrial firms. Engineering societies should consider requiring continued education for professional engineers to retain their licenses.

5. Federal policy should encourage the adoption of information technology in engineering functions in order to be able to make more effective use of the existing engineering work force.

6. More information and research is needed about the utilization of engineers in industry. Little is known at the present time about the impact of measures taken to improve industrial competitiveness on the activities and the productivity of engineers.

7. More research should be conducted on the determinants of retirement and career choice decisions in order to understand better the implications of existing and future demographic patterns.

8. More information is needed about the extent and impact of in-service and continuing education programs and how they interact with the rapidity with which skills, learned while acquiring the engineering degree, become obsolete.

9. Our ability to formulate effective policy with respect

to the education and utilization of engineers requires better understanding of current and future job openings, their determinants, and the types of skills required to fill them effectively. Our inability to compile appropriate information to illuminate key issues arises in large part from the sporadic and discontinuous attention that has been given to them in the past.

10. We should learn more about the management of the engineering function in industry, the incentives applied to encourage better engineering education, and the applicability of postgraduate engineers in industry. Case studies of this issue would be appropriate.

11. Computer science and engineering manpower data should be more carefully prescribed and collected.

12. More information is needed on individuals who do engineering work but who have no engineering degrees. Special studies of this group would be worthwhile.

13. The Committee recommends deeper studies of the quality of engineering work produced by degreed engineers as compared to that of nondegreed workers. The feasibility of such studies should be assessed. Some comparative international data may be available, and further studies in these areas should be stimulated, especially in view of the concerns over international competition. The relative number of engineers used by our strongest industrial competitors should also be studied.

APPENDIX A
RELATED TABLES

APPENDIX TABLE 1: Engineering Employment, 1972-1986 (thousands)

Year	Total Employed*	Employed in Science or Engineering**	Ratio
1972	951	887	.932
1976	1,372	1,278	.931
1978	1,539	1,427	.927
1982	1,847	1,719	.931
1984	2,214	2,062	.931
1986	2,440	2,243	.919

* NSF definition.
**As defined in this report.
SOURCES: National Science Foundation; Unpublished tabulations, Office of Scientific and Engineering Personnel.

APPENDIX TABLE 2: Percentage of Employed Engineers, by Age, 1972 and 1982

Age	1972	1982
Under 25	2.5	1.2
25 to 34	29.6	28.0
35 to 44	30.3	30.8
45 to 54	25.0	22.2
55 to 64	10.3	15.4
65 and Over	2.4	2.4
TOTAL	100.00	100.00

NOTE: These data describe the age distribution of those who either reported engineering as their occupation or had degrees in engineering.
SOURCE: Unpublished OSEP tabulations.

APPENDIX TABLE 3: Trends in Engineering Pipeline Variables, 1972-1986

Year	1 Age 18-21	2 College Enrollment	3 HS Grads (t-1)	4 1st Year Enrollment	5 Engineering Enroll(t-4)	6 Engineering B.S.
1972	15517	9214.8	2937	2171.3	77.5	44.2
1973	15910	9602.1	3001	2248.1	74.1	43.4
1974	16261	10223.7	3030	2392.9	71.6	41.4
1975	16674	11184.9	3073	2543.6	58.6	38.2
1976	16995	11012.1	3133	2377.2	52.1	38.0
1977	17225	11285.8	3148	2431.6	51.9	40.1
1978	17406	11260.1	3155	2422.4	63.4	46.1
1979	17505	11570.0	3127	2538.1	75.3	52.6
1980	17553	12096.9	3117	2625.1	82.2	58.1
1981	17446	12371.7	3043	2636.2	88.8	62.9
1982	17304	12425.8	3020	2505.0	95.8	67.0
1983	16911	12464.7	3001	2444.0	103.7	72.5
1984	16384	12241.9	2890	2357.0	110.1	76.9
1985	15810	12247.0	2773	2292.0	115.3	78.0
1986	15252	12398.0	2683	*	115.3	78.0

	7 College Enrollment Age 18-21	8 1st Year HS t-1	9 Engineering Enrollment 1st Year
1972	59.4	73.9	2.4
1973	60.4	74.9	2.3
1974	62.9	79.0	2.6
1975	67.1	82.8	3.0
1976	64.8	75.9	3.5
1977	65.5	77.2	3.7
1978	64.7	76.8	4.0
1979	66.1	81.2	4.1
1980	68.9	84.2	4.2
1981	70.9	86.6	4.4
1982	71.8	82.9	4.6
1983	73.7	81.4	4.5
1984	74.7	81.6	4.5
1985	77.5	82.7	4.5
1986	81.3		

* Data not available.

NOTE: Column 7 = (column 2 divided by column 1) x 100; column 8 = (column 4 divided by column 3) x 100; column 9 = (column 5 divided by column 4) x 100.

SOURCES: Center for Education Statistics, *Digest of Education Statistics*, Washington, D.C.: U.S. Government Printing Office, 1987; U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States*, Washington, D.C.: U.S. Government Printing Office, 1986; Engineering Manpower Commission, *Fact Book on Higher Education*, New York: EMC, 1987.

APPENDIX TABLE 4: Trends in Incomes of Professional, Technical, and Kindred Workers and the Consumer Price Index, 1972-1986

Year	Average Income	Consumer Price Index
1972	$13,542	125.3
1974	14,873	147.7
1976	16,939	170.5
1978	19,729	195.4
1980	23,026	246.8
1982	27,940	289.1
1984	31,423	322.2
1986	34,503	328.4

SOURCES: U.S. Department of Commerce, Bureau of the Census; and U.S. Department of Labor, Bureau of Labor Statistics.

APPENDIX TABLE 5: Ratio of Engineers' Salaries to Incomes of Professional, Technical, and Kindred Workers, 1972-1980

Year	Number of Years Since Baccalaureate				Professional Engineers/ PTK
	0	6	15	25	
1972	0.79	1.05	1.33	1.49	1.19
1974	0.82	1.06	1.37	1.51	1.23
1976	0.84	1.09	1.41	1.58	1.25
1978	0.81	1.09	1.44	1.60	1.20
1980	0.85	1.09	1.38	1.52	1.21

SOURCES: U.S. Bureau of the Census, Engineering Manpower Commission, and Bureau of Labor Statistics.

APPENDIX TABLE 6: Ratio of Engineers' Salaries to Incomes of Professional Specialty Occupations, 1982-1986*

Year	Number of Years Since Baccalaureate				Professional Engineers/ Professional Specialty Occupations
	0	6	15	25	
1982	0.86	1.10	1.37	1.50	1.17
1984	0.83	1.06	1.31	1.41	1.12
1986	0.83	1.08	1.39	1.53	1.14

* This table is a continuation of Appendix Table 5. However, it should be noted that in 1982 the taxonomy was changed such that "professional specialty occupations" replaced "professional, technical, and kindred workers."

SOURCES: U.S. Bureau of the Census, Engineering Manpower Commission, and Bureau of Labor Statistics.

APPENDIX TABLE 7: Ratio of Engineers' Salaries to Weekly Earnings of Workers in Private, Nonagricultural Industries, 1972-1986*

Year	Number of Years Since Baccalaureate				Professional Engineers/ Workers in Private, Nonagricultural Industries
	0	6	15	25	
1972	1.56	2.08	2.64	2.95	2.36
1974	1.57	2.04	2.64	2.91	2.36
1976	1.62	2.10	2.72	3.04	2.42
1978	1.58	2.11	2.78	3.09	2.33
1980	1.67	2.14	2.71	2.98	2.36
1982	1.80	2.30	2.87	3.14	2.44
1984	1.78	2.27	2.80	3.02	2.41
1986	1.88	2.44	3.14	3.47	2.59

* Weekly earnings were multiplied by 50 weeks.

SOURCES: U.S. Bureau of the Census, Engineering Manpower Commission, and Bureau of Labor Statistics.

APPENDIX B
AGENDA

WORKSHOP ON INDICATORS OF THE QUALITY OF THE PERFORMANCE OF ENGINEERS

August 20, 1987

8:00	Continental Breakfast	
8:30	Welcome	*Alan Fechter,* Executive Director, Office of Scientific and Engineering Personnel
	Overview of Study and Purpose	*Harrison Shull,* Chairman, Committee To Study Engineering Labor-Market Adjustments
	Data Used in the Study	*Alvin Cook,* Consultant
9:00	*Panel Discussion: Quality of Performance of Engineers from Different Perspectives*	
	Economics:	*W. Lee Hansen,* University of Wisconsin
	Sociology:	*Robert McGinnis,* Cornell University
	Industrial Psychology:	*Alan Porter,* Georgia Institute of Technology
	Case Studies:	*Gerald I. Susman,* Pennsylvania State University
10:30	*Break*	
10:45	Open Discussion	
12:00	*Lunch in NAS Refectory*	
1:00	*Concurrent Sessions: Evaluation of Engineering Personnel*	
	In Academia:	*F. Karl Willenbrock,* American Society for Engineering Education
	In R&D Industries:	*James Bogard,* United Technologies Center
	In Non-R&D Industries:	*Alvin J. Bernstein,* General Electric Company
2:15	*Break*	
2:30	Open Discussion	
3:30	Concluding Remarks	
3:45	Adjournment	

APPENDIX C
PARTICIPANTS

WORKSHOP ON INDICATORS OF THE QUALITY OF THE PERFORMANCE OF ENGINEERS

August 20, 1987

Dr. Robert Armstrong
Manager, Professional Staffing
Employee Relations Department
E. I. DuPont de Nemours

Dr. Pamela Atkinson
Fellow
National Academy of Engineering

Dr. Jesse Ausubel
Program Officer
National Academy of Engineering

Ms. Yupin Bae
Research Assistant
National Academy of Sciences

Mr. Joel L. Barries
Study Director
National Science Foundation

Dr. Alvin J. Bernstein
Manager, Employer Relations and Communications Operations
General Electric Company

Dr. James Bogard
Manager, Corporate Technology Planning
United Technologies Research Center

Dr. Dennis Chamot
Associate Director, Professional Development
AFL-CIO

Mr. Porter Coggeshall
Associate Director, Report Review Committee
National Academy of Sciences

Dr. Eileen Collins
Study Director
National Science Foundation

Dr. Dale Compton
Senior Fellow
National Academy of Engineering

Dr. Esther Conwell
Research Fellow
Xerox Corporation

Dr. Alvin Cook
Independent Consultant

Ms. Dee Cooper
Project Secretary
National Academy of Sciences

Dr. Robert C. Dauffenbach
Oklahoma State University

Ms. Linda S. Dix
Staff Officer
National Academy of Sciences

Mr. Richard Ellis
Executive Director
Engineering Manpower Commission

Mr. Alan Fechter
Executive Director
Office of Scientific and Engineering Personnel
National Academy of Sciences

Dr. Michael Finn
Oak Ridge Associated Universities

Mr. Ted Friel
Independent Consultant

Dr. Frederick W. Garry
Vice President, Corporate Engineering and Manufacturing
General Electric Company

Dr. Jerrier Haddad
IBM (retired)

Dr. W. Lee Hansen
University of Wisconsin-Madison

Mr. Dale B. Hartman
Hughes Aircraft Company

Ms. Ruth Hatfield
Allen Corporation

Dr. Ramchandran Jaikumar
Harvard University

Ms. Lora Langmead
IEEE

Mr. James F. Lardner
Vice President
Deere and Company

Dr. Anita LaSalle
National Science Foundation

Mr. George Lawrence
Army Research Institute

Dr. William LeBold
Purdue University

Mr. Leonard Lederman
Section Head
Div. of Science Resources Studies
National Science Foundation

Dr. Robert McGinnis
Director, Institute for Social
and Economic Research
Cornell University

Dr. Nancy Naismith
Office of Technology Assessment

Mr. Rolf Piekarz
Section Head
Div. of Policy Research & Analysis
National Science Foundation

Dr. Alan L. Porter
Georgia Institute of Technology

Dr. Herbert Rabin
Director, Engineering Research
Center
University of Maryland

Dr. David Reyes-Guerra
Executive Director
Accreditation Board for Engineering and Technology

Dr. John E. Rudzki, Jr.
Associate Program Director
National Science Foundation

Dr. David Sheetz
Director of R&D
Dow Chemical

Dr. Harrison Shull
University of Colorado-Boulder

Dr. Gerald I. Susman
Pennsylvania State University

Ms. Betty M. Vetter
Executive Director
Commission on Professionals
in Science and Technology

Dr. Donald Weinert
Executive Director
National Society for Professional
Engineers

Dr. F. Karl Willenbrock
Executive Director
American Society for Engineering
Education

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QUALITY OF PERFORMANCE AMONG ENGINEERS: THE PERSPECTIVE FROM ECONOMICS

W. Lee Hansen
University of Wisconsin-Madison

INTRODUCTION

What insights can the discipline of economics, particularly the specialty of labor economics, offer on the quality of the performance of engineers and possible indicators of such performance? This is an intriguing new question that, to the best of my knowledge, has not been asked in the long history of concern about the labor market for engineers. Considerable attention has been given to defining engineers, observing changes in the number and composition of engineers, and analyzing the labor market for engineering personnel. In all of this work, the focus has been on numerical counts of engineers and the earnings of engineers with differing characteristics; at best, there has been only passing reference to the quality of their performance.

In an attempt to fill this gap in our knowledge, this paper surveys from the vantage point of economics what is known about the quality of the performance of engineers. The paper begins by discussing the role of engineers in the production process, offers some general observations about the labor market for engineers, moves on to discuss the linkage between pay and performance for engineers, then examines the range of possible adjustments to sudden changes in the labor market for engineers, and finally offers several suggestions about the types of indicators that might be useful for assessing the quality and flexibility of the nation's stock of engineers.

THE ROLE OF ENGINEERS IN PRODUCTION

Engineers play a multifaceted role in our economic system. On the one hand, they are employed in the production process to produce an array of outputs, including a variety of both goods and services. For an employer of engineers, the task is that of finding the most efficient ways of using this costly resource. This involves effective utilization of the talents and skills of engineers so as to minimize the costs of this scarce labor input; it also requires that engineers be rewarded for the value of what they produce. At the same time, the larger task of engineers is to devise new equipment, techniques, and processes that enhance the efficiency and productivity of other workers who turn out the goods and services demanded by ultimate consumers. In this sense, engineers add to the productive capital of the economy and help to move the production frontier outward. To achieve this objective, employers of engineers must provide the guidance and resources that will, in cost-effective ways, enhance the possibility of producing new goods and services and also bring about cost savings in producing the existing array of goods and services. These productive activities are carried out by individuals in various settings--teachers and researchers in academic institutions, research and development specialists in nonacademic organizations, and line professionals in nonacademic organizations. In this sense, engineers represent one of our most crucial forms of human capital. Their knowledge and skills are used in direct production and also in producing new physical and human capital that is employed by other workers in direct production.

Engineers play still another role through the production of new engineers. A small group of engineers with advanced training devotes its attention to this task. Some fraction of newly produced engineers must be offered additional training as instructors so as to assure the reproduction of future generations of engineers and, in turn, future instructors of new engineers. Meanwhile, engineers with considerable experience must devote some of their efforts to providing on-the-job training to less experienced engineers so that the latter group can become more proficient and knowledgeable about the work they do. Thus, a not insignificant part of the engineering labor force is involved (a) in the direct production of new engineers and of new engineering teachers who will train future engineers and (b) in providing training to less experienced engineers so as to enhance their productivity as engineers. From a social standpoint, it is essential to apply cost-effective approaches in the production of new engineers, in the advanced training of new instructors of engineers, so as to ensure that newly trained engineers in the future will be more productive than their predecessors, and in the on-the-job training of less experienced engineers, so as to ensure that they can become even more productive.

The point is that engineers involved in production, education, advanced training, and on-the-job training produce direct outputs as well as outputs that become inputs to the production of direct outputs in the future. All of this may seem rather obvious. Yet it is important to stress this wide range of activities as we undertake the search for measures of performance.

How can we try to isolate the productivity of engineers engaged in this diverse range of activities? Economists naturally think of applying production-function analysis. This enables us to view output as the end result of combining an array of inputs, which are transformed through the production/education/advanced training/on-the-job training process into an appropriate form of output. Even if we could establish the dimensions of the input-output relationships and thus be able to select some "best practices" approach, we would not necessarily be satisfied because we must also take into account differences in the costs of the various inputs used. The greatest efficiency in combining physical outputs may be at odds with combining these outputs in the least-cost fashion.

We know almost nothing from the production function literature about the relative contribution of engineers who are engaged in any of the major activities described above. The outputs of interest have not been identified with any precision. The various inputs are often difficult to specify. The available production-function models are usually too simple to embrace the complex and subtle relationships that link inputs and outputs. And finally, the data on inputs, outputs, and their linkages are grossly underdeveloped, for the various reasons listed above. Hence, any effort to rush out and estimate production functions is unlikely to yield much of interest or value.

GENERAL OBSERVATIONS ON REWARDS FOR ENGINEERS

The operating assumption economics is that, on average, workers are rewarded for the value of what they produce. In a sense, the compensation--wages and salaries as well as fringe benefits--that people receive for their labor is the supreme measure of performance. Compensation from work enables individuals to command the resources that they need to live satisfying lives. Compensation is also widely viewed as an indicator of people's worth in this world; in short, it is a common measure of prestige. While there is clearly more to life and to the productive potential of individual workers than the amount of their compensation, economists have focused on the wage and salary component because of its prime importance in understanding how labor markets work.

The phrase used above, "the value of what [people] produce," is itself ambiguous. What people produce is reasonably clear when a specific physical output is the result of their work. Putting a dollar value on that output is typically much more difficult because of the jointness of production--that is, the fact that the production of some output usually involves the collaboration of a number of different workers, not to mention other types of input such as materials and capital. When what workers produce is less specific and tangible and is perhaps multidimensional in its nature, difficulties arise in specifying that output. Perhaps the term "performance" is as close as we can get to describing the output of such workers. In a sense, performance is a proxy for output, as reflected in the language of "job evaluation" and "job performance" from the personnel management field. This usage may not be inappropriate when applied to engineers. Their output involves performing a variety of functions, among them research, management, design, operations, and sales--all of which contribute to the output of their organization but in ways that are not easily isolated or described. This lack of well-defined outputs contributes to the difficulty of attaching a value to the work they do.

Even if we accept the proposition that, on average, workers are paid for their performance, the likelihood is low that all, or perhaps even most, individuals are paid amounts equivalent to the value of what they produce. Some individuals will be paid salaries greater than the value of what they produce, and others will be paid less. The exact relation between actual salaries and the value of what workers produce remains unknown. The reasons that salaries are likely to deviate from the value of what workers produce are numerous, and frequently they are lumped together under the term "market imperfections." There are several types of market imperfections: (1) elements of monopoly and monopsony power may lead to systematic divergences between the value of a worker's marginal product and the wage that he or she is paid; (2) the considerable differences between seemingly similar individual workers and between seemingly similar jobs are so great that it becomes difficult for outsiders to make comparisons among them to determine how closely the pay received by individual workers is matched to their performance; (3) making an assessment of the value of what individual workers produce is difficult and costly, both for employers who decide on what to pay workers and for workers who attempt to assess the appropriateness of their pay; and (4) barriers to ending employment relationships--for workers, the costs of finding new jobs, and for employers, the costs of finding replacements, compounded by a variety of legal, financial, and other barriers to withdrawing from an employment relationship. In addition to these standard caveats, there is no assurance that the current condition of the labor market is stable --that is, the market may be adjusting to some outside change, such that earnings today may not bear a direct relationship to earnings yesterday or tomorrow.

For these reasons there are opportunities for individuals to improve their economic situation and for employers to improve the effectiveness and performance of their labor force. This gives rise to some frictional level of job changing by workers and of worker turnover for employers. If, however, changes occur in overall salary differentials as a result of some outside change, such as a demand shock, labor mobility and turnover will increase as additional opportunities become available to workers. Whatever the case, there need not be responses by all workers or by all employers. As long as some of them respond, forces are set into motion that reallocate labor and thus improve the efficiency of the labor market.

Aside from the effects of job mobility and employee turnover, the link between current earnings and current performance is not as straightforward as the above description suggests. An important reason is that employment usually involves an implicit contract between a worker and an employer for a substantial time period. The essential point is that because the employment relationship is expected to be of long duration, there is need to ensure that compensation equals the value of what a worker produces over the career of the worker rather than on a week-to-week or even year-to-year basis. This becomes most apparent when we think of the costs that employers incur when they hire new workers and when they train them, as exemplified by human capital theory.

This situation can be illustrated as follows. Because of the costs of recruiting new employees, an employer cannot typically force these costs onto employees either before or immediately after hiring them. Instead, these costs are recouped by paying the worker less than the value of what he or she produces over some longer period until these costs are fully recouped. The same applies to firm-specific, on-the-job training provided by the employer. Such training is costly; and for the employer to recoup these costs, it is essential that the newly trained worker continue the employment relationship, receiving wages that are less than the value of what the worker produces, at least until the training costs are recouped. Similarly, because workers do not want to have to reenter the job market each year and thereby incur the costs of searching for new employment, they expect to and indeed are willing to pay some of the costs of both recruitment and training in their present jobs. This is accomplished by their receiving pay that is less than the value of what they produce, at least until these costs are fully recovered by the employer.

Still another dimension to these employment relationships affects the linkage between what workers are paid and the value of what they produce. In order to ensure that valued employees do not leave and take with them the valuable training and experience that they may have acquired on the job, employers will try to "lock" them into an employment relationship by offering increased compensation but in the form of, say, retirement benefits that cannot be converted into immediate cash. Indeed, employees often prefer sacrificing some of their current compensation for delayed compensation, that which comes after they have retired from the labor force. Not only does this help smooth out their lifetime income-consumption pattern, but it also obviates the need for them to save for retirement.

Of course, there will be differences among the several categories of engineers. Academic engineers who have published extensively will have independent reputations and are more likely to be sought by other employers than others who are excellent teachers but who have not been widely published; teaching reputations are much more difficult to publicize in the engineering labor market. R&D engineers who develop patentable processes and products can also be valued more easily by other employers because the evidence of what they have done can be studied independently of the individual. Non-R&D engineers produce output that is most specific to their employer and, hence, face greater difficulties in disseminating information about their productivity and performance.

Generalizing these several dimensions of human investment theory and the theory of implicit contracts produces the typical length-of-experience earnings curve. This curve rises steeply in the early years, rises progressively more slowly with additional years of experience, and then displays a sharp drop at retirement. To the extent that pension benefits are provided by the employer, the curve displays a flat or perhaps rising tail in retirement. A representation of this curve is shown in Figure 1. While there may be one or more years when earnings happen to match the value of what is produced, the common assumption that earnings' profiles reflect the value of what workers produce is misplaced. About all that we can say, then, is that workers are, on average, paid the value of their marginal product over their lifetimes.

All of this has become institutionalized in the formal salary schedules now so pervasive for engineers in whatever sector they work. These schedules, shown in Figure 2, provide a well-defined series of

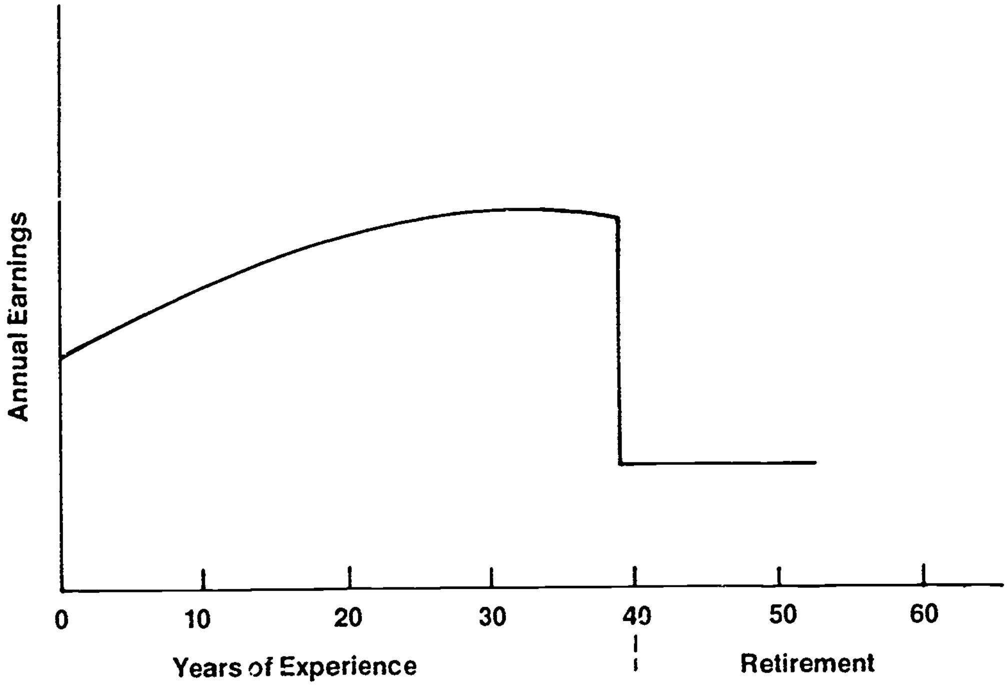

Figure 1. Cross-section of a typical life-cycle earnings' profile.

Figure 2. Cross-section earnings' profiles for different jobs.

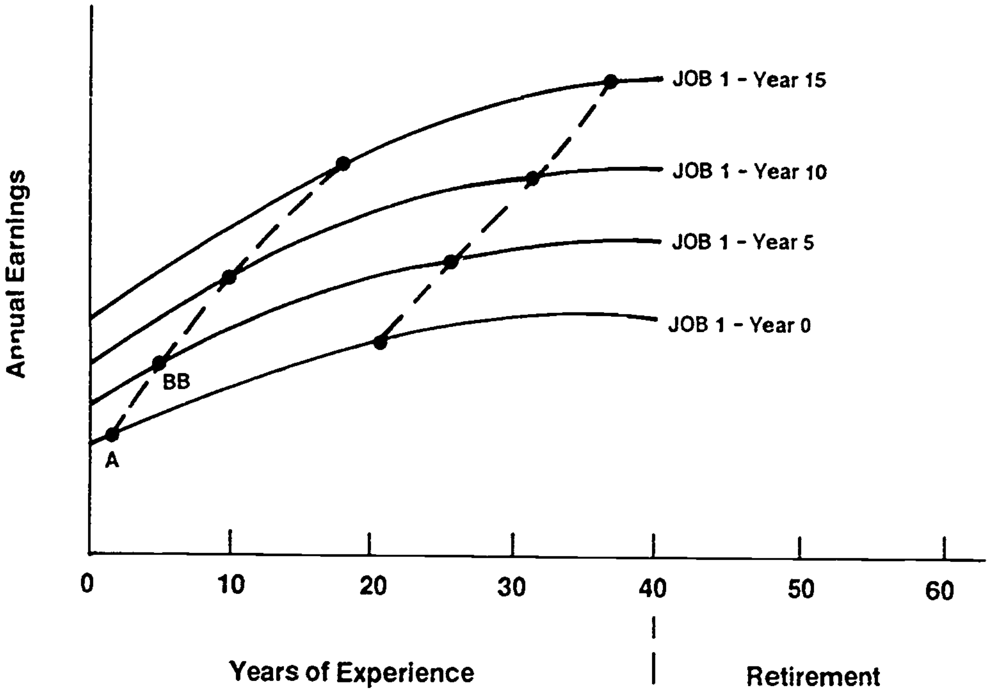

Figure 3. Successive cross-section earnings' profiles for same job.

annual salary increases that are tied to years of experience. Individuals move along these schedules (movement from A to B); outstanding performance can bring accelerated movement along the schedule (movement from A to C); and promotions can boost people onto higher paying schedules (movement from A to D). These schedules, however, are not static. They are adjusted upward each year or so because of increases in productivity, inflation, and the like, as shown in Figure 3. As a consequence, the actual experience earnings' profile is steeper than is implied by the cross-section relationships; instead of the movement from A to B in Figure 2, the movement will be from A to BB in Figure 3.

Employers can be viewed as having moved to establish salary schedules because of the difficulties and costs of assessing individual performance. As these salary schedules became more pervasive. and as an industry of job evaluators develops and increasingly gears its recommendations to the salaries that it observes in the market place, the schedules established by different firms have become increasingly similar. However, salary schedules are likely to be least prevalent in academic institutions, where engineers engage in extensive research activity and where differences in performance are most clearly evident. And they are likely to be most prevalent for line engineers, whose performance is least susceptible to outside evaluation.

While salary schedules are convenient for many of the reasons already mentioned, they greatly reduce the flexibility needed to link salaries to performance and to maintain that linkage over time. The rigidity of the schedules makes it more difficult for employers to recognize the superior performance of their outstanding workers because doing so requires deviating from the accepted salary schedule. To the extent that these talented people cannot be adequately compensated, they may search out and then accept other jobs that put them on higher, and perhaps also steeper, salary schedules. Because weak performers are likely to be more generously rewarded within the organization than they would be by the market place (e.g., by another firm), they will have little or no incentive to leave their present jobs. As a consequence, firms that attempt to "grow their own" talent and utilize well-defined salary schedules face the prospect of losing their most productive personnel and consequently retaining their least productive personnel. Firms that need to attract additional personnel will have to go out and bid for them in the market place by offering higher salaries.

THE PAY-PERFORMANCE LINKAGE

Despite all these difficulties, there has been considerable emphasis on using job performance ratings as a basis for salary increases. This is reflected by the development of job evaluators and by the increasingly formalized structures that managers must use in evaluating their employees for salary increases. Relatively little research appears to have been done showing how these evaluations affect actual salary increases. Economists, surprisingly, have given considerable attention to investigating the determinants of the annual earnings of engineers, incorporating into their analyses, whenever possible, measures of performance. The fragmentary evidence assembled by economists suggests that the link between job performance and earnings is quite weak; whether this is the result of the limited nature of the extant studies remains unclear.

Single-Equation Earnings' Model

In viewing the impact of performance on earnings, economists typically employ two approaches. One approach is to estimate a single-equation earnings' model using multiple regression analysis, where:

$$(1)\quad \ln E_i = f\ (P_i C_i \epsilon_i)$$

> where $\underline{E}$ is the log of earnings, $\underline{P}_i$ is a vector of performance indicators, $\underline{C}_i$ is a vector of control variables, and ϵ_i is the error term

The partial regression coefficients for the performance indicator(s) express the percentage effect on earnings of a unit difference in the performance indicator after controlling for other variables, $\underline{C}_i$, that are of no particular interest but which may obscure the true relationship between earnings and performance. Unfortunately, the performance indicators available and typically used are extremely limited. In the absence of good performance indicators, these studies might include as independent variables such characteristics as experience and age-squared (to reflect the progressive slowing in the rate of increase in earnings), years of schooling (to reflect human capital), and gender and race-ethnicity (to capture the effects of discrimination). Control variables might include such items as region and industry so that the effect of the performance indicators will not be contaminated by these other variables. In a few cases information is available on more direct indicators of performance. For academic engineers this might include numbers of publications, patents, teaching evaluations, administrative duties, consulting activity, and the like. For nonacademic engineers the available information is typically even less abundant; as a result, information on job functions performed might have to be substituted for more direct measures of performance. On the other hand, information on outputs such as patents might be available.

The single-equation approach implies that all of the independent variables have direct effects on the dependent variable--in this case, earnings. To deal with the fact that the relationships between all variables are not linear, interaction effects can be introduced to capture these relationships. Nonetheless, this approach forces an extremely simple analytic structure on the data.

Multiequation Performance-Earnings Model

To overcome this shortcoming, another approach can be employed. This calls for using a multiequation performance-earnings model, where:

(2a) $\text{In } P_i = f1\ (D_i C_i \epsilon_i)$, and
(2b) $\text{In } E_i = f2\ (P_i I_i \epsilon_i c_i)$

where $\underline{P}_i$ is the log of the performance measure, $\underline{D}_i$ is a vector of the determinants of performance, $\underline{C}_i$ is a vector of control variables, ϵ_i is the error term, $\underline{E}_i$ is the log of earnings, $\underline{P}_i$ is the predicted value of performance from equation (2a), and $\underline{I}_i$ is a vector of independent variables affecting $\underline{E}_i$.

It is one thing to propose this second approach and quite another to implement it. While earnings can be clearly defined and measured, the same cannot be said for performance. Typically, performance is a multidimensional concept. In addition, we must separate those variables affecting performance from those affecting earnings, though some variables may affect both; an example might be years of schooling as a determinant of performance (capturing an individual's fundamental knowledge of engineering) and as a separate determinant of earnings (capturing an individual's qualifications that affect his or her salary directly via job qualification requirements). Finally, we still face the task of separating the contribution of the engineer from that of allied workers, not to mention from that of other, nonhuman inputs such as capital. This is the classic problem of jointness in production: How does one separate out the impact on output of one among a number of interrelated inputs? Still more complicated multiequation models can be constructed to explore the determinants of particular independent variables in the performance equation (2a). An example might be the selection process by which employees are hired.

The explanatory power of these models is typically quite limited. And the practical significance of the regression coefficient from these studies is questionable if, in fact, the salaries of engineers reflect the shape of the underlying salary schedule, which captures, at best, quite imperfectly the performance levels of particular individuals.

Still another approach tries to develop a full-blown supply-demand model of the labor market to estimate the effects of both supply and demand shifts on earnings and employment. These simultaneous equations models have not progressed very far as yet, for many of the reasons already mentioned.

ADJUSTMENTS TO CHANGE

The foregoing discussion has attempted to explain differences in salary and performance rather than changes in these differences resulting from shifting labor-market conditions. Explaining differences based on cross-section data is important because it can help to give some feel for what might be the effect of changes in labor-market conditions. But too frequently, leaps of inference are made about the effects of changes based on the effects of differences. For this reason it seems important to try to correct this imbalance by outlining the kinds of adjustments that we might anticipate in the face of changes in labor-market conditions.

We begin by concentrating on demand-side changes, which involve determinations by employers about how to adjust and deploy their labor force in the face of external changes. Demand-side changes are perhaps most critical because they typically occur rapidly, they quickly generate labor-market effects, and above all they excite public policy attention, which frequently leads to calls for governmental action.

When there are sudden increases in demand for the services of engineers, it is conceivable that a "shortage" of engineers will develop--meaning that, in the short run, additional engineers cannot be induced into the labor market even if more attractive salaries are offered. Of course, some adjustments may have already occurred as people with engineering-like knowledge and skills are attracted from related fields, retirees are called back to work, and some engineering graduates who might have decided not to enter engineering employment reconsider their decisions. Once this slack is taken up, more serious adjustments must be contemplated by employers.

Employers have various options. One is to find ways of increasing output without using additional units of labor (more people); another is to increase the amount of labor provided by the same number of people; still another is to decrease attrition from the work force; and the last is to increase the number of new recruits to the work force. Each of these is discussed in turn.

Cope Without Additional Workers

There are various possibilities. In addition to substituting capital and other types of labor for engineers, contracting out, and curtailing how much is produced, efforts can be made to increase worker productivity or performance. The test is whether productivity goes up. To the extent that it does, workers will benefit through increased salaries.

Increase the Hours of Existing Workers

The most obvious move for an employer is to increase the number of hours that people are required to work and, if need be, increase the pay for this work. In addition, workers can be urged to work harder during the hours that they do work. Exhortations of this kind will be more favorably received to the extent that workers will share in the gains.

Reduce Attrition Among Workers

To the extent that additional workers are desperately needed, retirements can be deferred, dismissals can be reduced, promotional possibilities can be enhanced, and efforts can be made to increase job satisfaction.

Increase Recruitment of New Workers

Recruitment can be facilitated by raising pay, searching more intensively, improving working conditions, and providing more flexible hours. In addition, it may be advisable to reduce hiring standards, to redesign jobs so that less qualified people can perform them, and to increase the amount of training provided to new workers.

This wide array of adjustment possibilities greatly complicates the task of trying to find indicators of performance. Moreover, the dimensions of these changes are so complex that they do not lend themselves to simple indicators. For example, if we think of the amount of formal schooling possessed by workers as a measure of the quality of the work force, then any adjustment that requires hiring "less qualified" (less educated) workers will represent a decline in performance. On the other hand, these less qualified people might be better trained in other ways and, hence, of the same quality. Or additional training could be provided to these less qualified workers to bring them up to par. This would involve some cost, of course, but could be seen as the least-cost method of adjusting to change.

CONCLUSIONS

This exercise illustrates once again how little we know about the performance of engineers. The available research is extremely limited, and little attention has been given to developing indicators of performance and incorporating them in the various kinds of analyses done by economists.

This failure may not be as devastating as it seems if we return to the theme of the opening section of the paper. The matters of ultimate importance are twofold. First, to what extent can the services of engineers be used more efficiently so as to reduce or at least hold down the rate of increase in the cost of producing goods and services in which engineers are important inputs? Second, to what extent can engineers be made more efficient in developing new products and techniques that will increase the productivity of other workers and, hence, expand the array of goods that can be produced and/or reduce the cost of goods already produced? How to assemble evidence on these questions is no easy task. My sense is that we will not be able to learn a great deal from macro-type studies. Nor will the analysis of existing micro data yield any rich harvest of results. The kinds of information needed for such studies do not exist.

My recommendation in the first instance is to conduct exploratory studies at the level of the firm to learn more about (a) what engineers do, (b) how their activities are linked to the production process, (c) how what they do contributes to the development of new goods and services, and (d) the cost-reducing effects of their efforts on other firms and groups of workers. The case studies of the kind proposed are not only difficult to do, but economists do not have the training that would enable them to carry out such studies. Matters are further complicated because of the low payoff in the profession to people who do studies of this kind. For all of these reasons, economists are predisposed against case studies even though an understanding of costs, production, and the like is essential to the design and implementation of case studies that will elicit the kinds of effects discussed in this paper.

In the meantime, what types of indicators can we suggest that will enhance our understanding of the performance of engineers? First, it would be useful to know more about the range and success of productivity-enhancing activities on the part of employers in their utilization of engineers. For instance, to what extent have these activities relied on what might be called motivational efforts, on work redesign, and on substitution of capital equipment? Second, what kinds of cost-reducing practices have employers developed in the utilization of their engineering work force? For example, to what extent have they been able to substitute less skilled labor, contract out for engineering services, or manage with fewer but different kinds of engineers? Third, what kinds of productivity-enhancing products, techniques, and the like developed by engineers have reduced the costs of other workers in producing goods and services and have expanded the range of products and services produced? To what extent have new technologies developed by engineers made for more efficient, lower cost production by other workers? What technologies? And in what industries? To what extent have new products developed by engineers enlarged the range of choices available to consumers? What products and in what industries?

I wish I could be more specific in offering concrete suggestions about how to proceed. It seems apparent that the potential contributions of the discipline await both a more detailed understanding of what it is that makes engineers tick and also highly detailed data that can highlight the dimensions of performance outlined earlier. This is a major undertaking--one that must begin at the bottom to develop, largely through case studies, our knowledge and understanding of the engineering-employment relationship.

INTERACTIONS BETWEEN LABOR-MARKET ADJUSTMENTS AND THE QUALITY OF PERFORMANCE IN ENGINEERING: A SOCIOLOGICAL PERSPECTIVE

Robert McGinnis
Cornell University

INTRODUCTION

The National Research Council's Committee on Engineering Labor-Market Adjustments (CELMA) was asked to investigate possible supply/demand imbalances in the U.S. labor market for engineers and any consequences for the quality of their performance. This broad objective appears to rest on a set of assumptions that includes these:

1. Each engineer and each engineering job carries a set of performance qualifications.
2. The quality of an individual engineer's performance on the job is a characteristic that is, at least, indirectly measurable and variable.
3. In general, the better the match between the required qualifications of the job and those of its occupant, the higher will be the quality of his or her job performance.
4. For a variety of reasons, there is cause to predict a near-term shortage of engineers in certain areas relative to demand for them in the U.S. labor market.
5. In consequence of (4), labor-market adjustments may lead to a growing mismatch between the qualifications required for a job and those of its occupant in a significant number of instances.
6. The result of (5) because of (3) would be an aggregate decline in the quality of performance in at least those areas of American engineering with the greatest supply/demand imbalances.

The last in this chain of assumptions is considered by many to be of vital importance to the American economy. This follows from the further assumption that its performance in the world market relies heavily on a scientific and engineering labor force of the highest quality.

The purpose of this paper is to examine at least some of these assumptions—especially the fourth—from a sociological perspective and to expose them to whatever pale light the perspective may generate. In fact, there are at least four such perspectives—overlapping, to be sure, but with distinct concerns--that may shed some light on the assumptions. These are labor force demography and the sociologies of occupations and professions, labor markets, and science.[1]

The concerns of demographers with the processes of birth, death, and migration that determine the size and composition of populations and their temporal dynamics are sufficiently well known to require no elaboration here. It should be noted, however, that demographic studies of the U.S. engineering labor force are virtually the sole province of federal agencies such as the National Science Foundation (NSF) (see, for example, NSF, 1985a, and NSB, 1985). Relative to academic studies of the engineering labor force, our libraries bulge with scholarly demographic studies of, say, reproductive patterns of indigenous Inner Mongolian females.

Sociologists of occupations and professions have closer intellectual ties with traditional sociological and social psychological analysis than with the analyses of massive secondary data sets that characterize demography. In one of the few investigations of U.S. engineers in this tradition (Perrucci and Gerstl, 1969), the index contains, under "engineers and engineering," subentries such as "commitment in," "extrinsic interest in," "family of," "personality characteristics of," "student subculture of," and "television viewing of." Although most of these topics are clearly out of the scope of CEIMA's concern, students of occupations and professions do touch on matters that have a bearing on our concern. These have to do with what may be more subtle job qualifications in some sectors, such as loyalty (to discipline versus to employer) and the value of autonomy.

Labor-market sociologists are relatively new kids on a block that formerly was the turf of economists. Many of the concerns of sociologists and economists in this area are identical--variability in wage rates, unemployment, career patterns. Still, the sociologists claim to be a different breed with new things to say. In a recent characterization, labor economists were said to follow the line of "neoclassical theory of wage determination and labor supply, with marginal productivity theory accounting for the demand side and human capital theory taking care of the supply side. In contrast, sociological research . . . [in this area originated in studies] describing socioeconomic attainment and social mobility processes for various population groups" (Sorensen and Kalleberg, 1981:49). The perspective of labor-market sociologists does have some possibly important messages for us. Their emphasis on the influence of background characteristics, such as parental education, on socioeconomic attainment cannot be ignored in the face of the changing demographic makeup of new entrants into the engineering labor force. Their stress on career mobility patterns should alert us to possible losses of highly qualified engineers from positions for which they are technically qualified to others, such as management, for which their qualifications may be less relevant.

In this array of sociological perspectives, there is one that can be particularly useful to CEIMA despite the fact that it has virtually nothing to say about engineering: that of the sociology of science. To

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[1] My own area of research falls in the intersection of labor-force demography and the sociology of science.

consider the almost literal cord that has been sewn by NSF and other federal agencies between science and engineering (S/E) would lead one to expect a wealth of information and guidance from research in the sociology of science about the careers of and labor markets for engineers. Quite the opposite, in fact, is the case. The "hot" areas for investigation by sociologists of science are those in which chases are on for discovery, paradigm change, and Nobel prizes. They appear to find engineers as uninteresting as they do the development side of research and development (R&D).[2] Despite this, the literature of the sociology of science has depth in areas that will be useful to CEIMA: those of job performance and quality. In fact, there is no other area of sociology with which I am acquainted that is so deeply involved in these topics. Therein rest several problems that are discussed below.

Finally, there is a sociological perspective that represents a set of skills rather than a substantive area of research: the methodological skills that enable one to carry out analyses and interpretations of large data sets such as those compiled by NSF. These skills are by no means the sole possessions of sociologists but are essential to implementing their perspectives in research.

The remainder of this paper examines selected issues in engineering labor-market adjustments from a sociological/demographic perspective. It is particularly concerned with trends in the composition of the engineering labor force and with implications of these changes for possible adjustments in the labor market. A final brief section considers the performance of engineers as a methodological problem and in one of three areas of particular interest to the committee, academe, despite the fact (and in part because of the fact) that it is the smallest of the major employment sectors for engineers.

ISSUES IN ENGINEERING LABOR MARKETS

A major issue before this committee was well expressed by Robert M. White, president of the National Academy of Engineering, in the foreword of a National Research Council report (NRC, 1984). After asserting that "our technically trained work force is of critical importance" to the well-being of the nation and its competitive position in world markets, Dr. White wrote:

> The issue seems to be a hardy perennial. We experience continuous cycles of perceived surplus and shortage. The basic cause is fairly clear: the demand for engineers fluctuates with rather high frequency, responding to economic conditions and other conditions that seem to change rapidly, while the supply side fluctuates with low frequency. It takes time to train an engineer; and the imbalances result-

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[2] The index to the collected papers of the preeminent American sociologist of science contains no references to engineers or engineering (Merton, 1973). For a notable exception, see LeBold, *et al.* (1983).

> ing when one tries to match a high-frequency demand with a low-frequency supply gives what we see as alternate surpluses and shortages.

To examine the implications of such surpluses and shortages and what, if any, labor-market adjustments may occur spontaneously or be induced as a result of them, it will first be useful to examine several questions about the engineering labor force. The questions that are examined here concern the definition(s) of an engineer, trends in the composition of the engineering labor force, the quality of projection models, and implications for labor-market adjustments.

What Defines an Engineer?

Debate about the proper answer to this question clearly could extend into the indefinite future and probably with little accomplishment. Who has the authority to provide the definition and make it stick is a simpler, if not better, question. The answer to this question is much more clear and precise: the National Science Foundation. Over the past decade NSF has been refining a set of definitions for S/E that might be called the "any two out of three algorithm." Most simply, the algorithm says that anyone who has at least two of the following three characteristics is an engineer: (1) a higher degree in one of the 13 fields recognized by NSF (including an associate degree for engineers), (2) employment in an engineering occupation, and/or (3) professional self-identification "based on total education and work experience" as an engineer.

In operation, the NSF algorithm, as implemented by Mathematica Inc., is somewhat complicated and merits scrutiny. For example, consider a person whose highest degree was in theater arts or some other non-S/E field. If that person had employment in and self-identification with an acceptable engineering or computer science field, then he or she would be defined as being an engineer or computer scientist. On the other hand, if a person with the same non-S/E degree satisfied both of the other two criteria with respect to, say, physics or sociology, the person would be classed as "out of scope" due to the lack of a degree in any S/E field. Thus, the algorithm might better be labeled "any two out of three—sometimes." It is difficult to imagine how these peculiarities of the NSF definition would have major impacts on counts of engineers in the labor force, but the possibility does exist and deserves study.[3]

A far more pressing problem than establishing the boundaries of the engineering work force is that of establishing a meaningful taxonomy of occupations and practitioners. To distinguish among engineers by a dozen or so field categories that reflect traditional academic de-

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[3] For a preliminary analysis of the algorithm's impact on counts in selected Ph.D. fields, see Citro (1987).

partments is to claim tacitly that these categories represent equivalence classes. And this, in my view, is at the heart of our incapability of getting an in-depth grasp of the nature of job skill requirements and practitioner capabilities. To argue that two jobs in electrical engineering carry essentially the same skill requirements, although the primary work activity of one is retail sales while the other is basic or applied research, is possibly naive. To argue that two individuals are equivalent because they both pass the NSF "two out of three" muster as electrical engineers, although one is a new entrant with a baccalaureate degree and the other is a Ph.D. with 20 years of professional experience, is patently naive.

In an evaluation of macro projection models, Hansen (1986) alludes to the problem of simplistic taxonomies. As an example of something closer to what is needed, he tells us that "one national recruiting firm that specializes in placing engineers utilizes a 55-item position code, a 37-item listing of areas of both what employers seek and what individual job seekers can do." It may be that far less depth of detail than this would be sufficient to permit the beginnings of meaningful analyses of performance requirements and capabilities. It may well be that large clusters of jobs turn out to be equivalent, even across some fields of S/E, and that clusters of workers are similarly equivalent in terms of the skills that they have acquired both in their education and on-the-job experience. Whatever the case, I am convinced that here is one area where an ambitious program of research needs to be launched if we are to come to an understanding of the assumptions about jobs and their occupants, of matches and mismatches, and of the bearing of these on quality of product that underlie the work of CEIMA. This line of research could also provide important information for the improvement of academic curricula and on-the-job training.

Vacant positions do not imply a labor shortage. Only when unfilled positions require skills that are not available from new entrants does a shortage of labor occur that would require market adjustments. If the skills are available elsewhere in the work force, then one form of adjustment may be feasible; if not, then others would be required. It is because we lack the necessary information about skills --required and available--that I suggest we do not know whether real shortages of engineers are likely to occur.

A special case of mismatch could have important implications for possible market adjustments: that of people with engineering skills in positions that do not require them. More than one in every five U.S. engineers is in a position of managing non-R&D activities. In 1982 this amounted to nearly a quarter-million workers, according to NSF (1984a, Table B-11). We can only speculate about whether these positions require skills that are peculiar to engineers and about whether their occupants could be moved effectively into areas of shortage. If others such as M.B.A.s or economists could be put into just a fraction of these positions and the current occupants moved into shortage areas for which they have the requisite skills, then a powerful form of market adjustment would be available. But, once again, to know whether such occupational mobility is feasible requires information about skills that is not available.

Composition of the U.S. Engineering Labor Force

By the middle of the 1980s, the employed engineering work force had passed the 2 million mark. In size, it is second only to teaching among the professions and is followed closely by science, whose numbers should exceed 2 million this year or next. The modal U.S. engineer is a white male U.S. citizen who is 42 years old. He has a baccalaureate degree in electrical/electronics engineering and works full-time doing product development for a firm that produces electrical equipment.[4] These modalities are changing, of course, some of them fairly rapidly. But it is a safe bet that the engineering work force in 2000 will closely resemble this snapshot—a shade less white, noticeably less masculine, considerably older—but otherwise much the same.

At least some of the compositional changes that are occurring have implications for labor-market adjustments in engineering. Among the most important of these changes are in the age, sex, race/ethnicity, and citizenship distributions of engineers. Of these, age is given by far the shortest shrift among watchers of S/E, such as NSF.

Age

An indicator of the relative lack of interest in the topic of age and aging in the S/E work force is to be seen in *Science Indicators, 1985* (NSB, 1985). In its 116 pages of tables, there appear only three that provide information on age, and one of these concerns the age of equipment. The other two describe the age distributions of Ph.D. or M.D. groups and are given just one brief paragraph in the text. That paragraph, however, is extremely important: it shows that 38 percent of doctoral engineers in academe in 1977 were under 40 years of age—the lowest among all reported fields of S/E (p. 104). By 1983 it had dropped 10 points. In contrast, the comparable percentages for computer scientists were 57 in 1977 and 48 in 1983.[5]

The age of a population is determined by its prevailing schedules of birth, death, and net migration. In a national work force, this translates into new entrants, attrition, and occupational and net international migration. The growth rates shown in Table 1 reflect average annual rates of 5.1 percent for engineers as against 6.9 and 16.6 for all scientists and computer scientists, respectively. Between 1979 and 1982, the annual growth rate of all B.S. and higher degrees in engineering from U.S. institutions was 7.1 percent (NSB, 1985, Appendix Table 5-3). This gives a picture of a healthy growth of new entrants relative to the work force. This is a reasonable comparison so long as

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[4] Where not otherwise specified, data are taken from one of the following sources: NSF (1984a, 1984b, 1985a) and National Science Board (1985).

[5] The literature is not clear as to whether a computer specialist is a scientist or an engineer. NSF treats them as scientists, often linking them to mathematicians. Other sources treat them as engineers.

TABLE 1: 1976-1983 Growth Rates and 1983 Concentration Ratios of Employed Scientists, Computer Specialists, and Engineers

Field	1976-1983 Growth Rate Total	1976-1983 Growth Rate Female	Percent Female, 1983	Female Concentration Ratio, 1983
All Scientists	59.0	111.0	24.6	--
Computer	193.4	372.8	27.9	1.13
All Engineers	41.4	195.8	3.3	--
Astronautical/ aeronautical	49.1	300.0	1.9	0.50
Chemical	48.3	192.0	6.4	1.94
Civil	44.4	1.9	2.0	0.62
Electrical/electronics	66.2	487.5	2.0	0.61
Mechanical	34.5	134.7	1.5	0.44
Other	27.8	272.5	5.4	1.65

NOTES: Concentration ratio is percent of field who are female relative to percentage of total who are female. Concentration ratio for computer scientists is relative to that of total scientists. All others are relative to total engineers.
SOURCE: National Science Foundation, *Science and Engineering Personnel: A National Overview* (NSP 85-302), Table B-9, Washington, D.C.: U.S. Government Printing Office, 1985.

one does not push it to the incorrect conclusion that the growth rate of new entrants is sustaining the growth rate of the work force. To evaluate the contribution of new entrants to growth in the labor force, we must take attrition into account and recalculate.

Clearly there was attrition over the period, but of an amount about which we can only speculate. Standard guesses put it at 1 to 2 percent per year.[6] A substantial fraction of this results from death or retirement, two of the important results of an aging work force. And U.S. engineers clearly are an aging group. Their 1982 median age of 42 years is greater than that of scientists (37 years) and considerably more than that of computer scientists (34 years). Perhaps more important from the perspective of attrition is the fact that 8.3 percent of employed engineers in 1982 were at least 60 years of age,

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[6] If moves out of engineering occupations into management and administration are included, I would guess that attrition of engineers from all causes is close to 5 percent (see note 16).

compared to 5.0 and 1.1 percent for scientists and computer specialists, respectively.[7]

I calculate that the 61,100 new engineering entrants in 1982 estimated by NSF represented about 3.4 percent of the engineering labor force employed in S/E (NSF, 1985c, Tables B-8 and B-2). If attrition occurred at 1 percent, then only 2.4 percent of the growth came from new entrants to S/E--and this assumes that all entered engineering occupations. The balance had to come from other sources. If attrition increases by a couple of points--as it must, due to age--we come close to the point at which new entrants represent only replacement, at best, with any growth coming necessarily from other sources. It is clearly important to understand how the supply side of the projection models handles attrition in this aging population, but the details appear to be unavailable.

There are great advantages of an aging work force in the wealth of professional experience possessed by older workers. There is little evidence that age actually carries with it a reduced productive capacity in science (see Reskin, 1979, for a thorough review) or career interruptions due to illness (Lewis, 1986). In the sociology of science, there is some concern about increased scientific conservatism and centralization of "gate-keeping" authority (Zuckerman and Merton, 1972), but these are side issues for present purposes. Evidently, the only real reason that an aging work force requires careful study from the perspective of needed labor-market adjustments is that of the increasing need for replacement that it represents. But even the relation between age and retirement plans has been further confused by recent retirement legislation. For such reasons, this is a changing characteristic of the engineering work force that merits particularly close examination.

Sex

The most spectacular change in the composition of the S/E work force is in gender, spectacular at least in terms of the relative growth of women in the work force. As Table 1 shows, during the 7 years from 1976 through 1983, employed women engineers grew by a rate more than 4.7 times greater than that of the engineering total (just over 5 times that of men). Such awesome growth rates brought women engineers up to 3.3 percent of the 1983 labor force. While their growth rate exceeds that of women in science, it falls far short of that of women in computing specialties (counted by NSF as part of science rather than of engineering). In 1976 there were almost equal numbers (21,400 and 20,600) of women in engineering and computer science, respectively (NSF, 1985c, Table B-10). By 1983 there were 54 percent more of the latter than the former.

As can be seen in Table 1, the growing numbers of women engineers

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[7] The reported age estimates are composites derived from several NSF data bases--including the 1982 Postcensal Survey, which estimated 8.8 percent of engineers as being at least 60 years of age (NSF, 1984a, Table B-18).

was far from uniformly distributed over the fields of engineering. The strongest rate of growth, not surprisingly, was experienced in those fields with the smallest base at the beginning of the period: electrical/electronics and astronautical/aeronautical. By the end of the period, a majority (53 percent) were in that peculiar field of engineering known as "other." There is no evidence of strong concentrations among types of employer, but a considerable amount among primary work activities (not shown in Table 1): the percentage of women in teaching was about twice that of men and the percentage of women doing reporting/statistical work/computing was three times that of men.

I am aware of no reason to doubt that the ranks of women in engineering will continue to grow, possibly even to the point where someday their numbers may become nontrivial. Insofar as this is the case, the growth has substantial implications for the labor market. Because of their recent entry into the labor force, they are extremely young, on average, compared to male engineers. In 1982 the median age of female engineers was 28 years as against the male median of 42 years.[8] Thus, while female engineers lack the experience of their male counterparts, they have the valuable asset of substantial expected longevity in their careers.

Age aside, there are important differences between career patterns of males and females in science, many of which quite likely are to be found in engineering as well. Women undergo far more significant career interruptions than do men. Among holders of doctorate degrees in the S/E labor force, for example, 17.3 percent of women report career interruptions of at least a year's duration as against 5.2 percent of men. The comparable percents in engineering are 11.4 and 3.7, respectively (Lewis, 1986). Additionally, they work at lower levels and receive smaller salaries than do men, which can be attributed in part, at least, to their relative youth. But it is more difficult to account for their frequent entry into occupations that are not even on the career ladder in science. And it is still more difficult to account for the fact that women in academic science are substantially less productive of research publications and receive fewer citations per publication than do their male academic counterparts.[9]

Gender differences in science may or may not signal similar differences in engineering. There is some evidence of greater parity today in engineering than in science, such as the near absence of differences in degree attainment in the former (NSF, 1984b, Table B-9).

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[8] The 14-year age gap between men and women in engineering compares with gaps of about 5 and 4 years in science and computer specialties, respectively (NSF, 1984a, Table B-18).

[9] For a penetrating review of gender differences in science and the hypotheses that have been examined to account for them, see Zuckerman, 1987. See also the other papers in Linda S. Dix (ed.), *WOMEN: Their Underrepresentation and Career Differentials in Science and Engineering* (Washington, D.C.: National Academy Press, 1987), especially that by J. Scott Long, which provides an excellent methodological critique of research in gender differences.

New entrants to engineering display little gender difference in their entry to the profession in terms of type of employer (LeBold, *et al.*, 1983). The differences in the numbers of publications and citations of men and women in science continue to puzzle sociologists but need be of concern only with respect to the small fraction of the engineering labor force in which research is conducted and publications are expected. Thus, there seems to be a single cause for concern about the growth in the number of women engineers: why it fails to keep pace with that in related fields, such as computer specialties.

The ethical imperative of opening the professions to women and minorities is sufficient reason for encouraging growth in the number of women engineers. Quite beyond this imperative, to do whatever can be done to encourage this growth represents sound strategy for those concerned with engineering labor markets. In this period of population decline among 18- to 24-year-olds, women represent a major, largely untapped market for the recruitment of new engineers. For these reasons it would be wise for CEIMA to recommend that research be carried out on careers of women in engineering to determine what fields, types of employment, and work activities optimize the productivity, rewards, job satisfaction, and security of women engineers.[10]

Race/Ethnicity and Citizenship

The recruitment of racial minorities into U.S. science and engineering is succinctly described by NSF:

> In 1984, blacks accounted for about 2 percent of all employed scientists and engineers, but 10 percent of total U.S. employment and more than 6 percent of all professional and related worker employment. Asians, on the other hand, represented almost 5 percent of the employed scientists and engineers but less than 2 percent of the overall U.S. labor force. (NSF, 1986:viii)

Among employed engineers in the same year, the picture was slightly more extreme: 1.7 and 5.3 percent were black and Asian, respectively. When these numbers are disaggregated by sex, the situation is changed. Less than 9 percent of the males but nearly 15 percent of the females were nonwhite. Of the female engineers, 4.1 and 8.2 percent were black and Asian, respectively. Among the small number of employed doctoral engineers in that year (61,500), 19.2 percent were nonwhite, including 17.1 percent Asian.[11]

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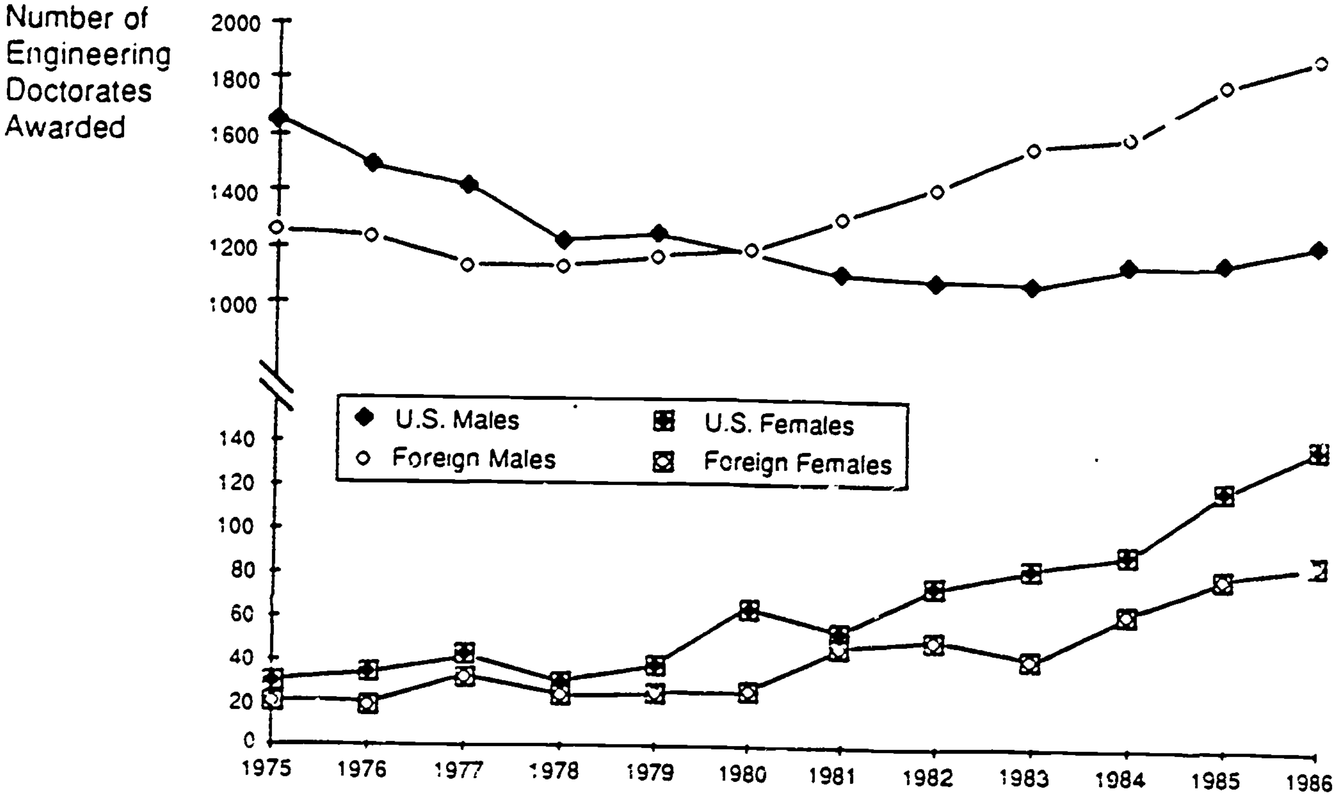
[10] For a thorough review of work completed and data bases that deal with these aspects of the labor force, see Kalleberg (1986).

[11] These NSF percentages on racial/ethnic composition are not necessarily accurate for two reasons: some racial and ethnic categories are not mutually exclusive and, like most of the data reported here, they are based on composite estimates. All data in this section are from the volume quoted. Counts of minorities in this paragraph were taken from NSF (1985c).



SOURCE: National Research Council, Doctorate Records File.

Figure 1. U.S. doctorate degrees awarded in engineering, by sex and citizenship, 1975-1986.

Across all fields of engineering, foreign citizens are about as likely to be encountered as are women. In 1984 they made up only 3.5 percent of the employed engineering work force in the United States (down from 4.2 percent in 1972).[12] Naturalized citizens, on the other hand, are much more conspicuous, making up about 13.7 percent of employed engineers in the same year (up from 5.2 percent in 1972). Foreign citizens are distributed quite uniformly as percentages of the engineering fields, with no clear concentration in areas of presumed shortage. Citizenship makes little difference in the modal employment sector: about 80 percent of all employed engineers were in the business/industry sector (NSF, 1985c, Table B-13), and about 82 percent of the foreign engineers were in that sector (Falk, 1987, Figure 5). In one critically important sector, foreign engineers, at 8 percent, were nearly 3 times more likely to be employed in education than was the total work force of engineers, at 2.7 percent. Falk does not report

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[12] Data dealing with citizenship, where not otherwise described, are taken from Charles E. Falk, "Foreign Engineers and Engineering Students in the United States," in Committee on the International Exchange and Movement of Engineers, *Foreign and Foreign-Born Engineers in the United States: Infusing Talent, Raising Issues*, Washington, D.C.: National Academy Press, 1987.

countries of origin for the foreign work force, but one can infer from the preceding discussion that they are predominantly Asian. Among foreign doctorate recipients in 1985, 74 percent were from Taiwan, mainland China, India, or Korea (Falk, 1987, Figure 17).

Level of education represents an important difference between foreign and U.S. citizen engineers. In 1982, foreign and naturalized citizens made up 17.2 percent of the engineering labor force. They represented 14.5 percent of those with bachelor's degrees, 22.3 of the master's, and 35.8 of the doctorate degree-holders (Falk, 1987, Figure 4). In 1981, for the first time in the history of any science or engineering field, the majority (53.8 percent) of engineering doctorate degrees went to foreign citizens. In 1985, half of the assistant professors of engineering in American colleges and universities who were under age 36 were foreign. These facts result in large part from increasing numbers of foreign students and decreasing numbers of U.S. citizens receiving doctorate degrees in engineering. Between 1975 and 1986 the numbers awarded to U.S. citizens decreased by 25 percent while during the same period the numbers going to foreign graduate students increased by 52 percent (see Figure 1).

The rapid growth of foreign citizens in the U.S. engineering labor force--especially within the higher levels of education--is creating concerns both within engineering and among policymakers. Among the former there are muted expressions of concern about this compositional change because of its possible effects on the job market for U.S. citizens, average salaries, and even on the quality of the work force. Among policymakers, concerns are expressed about American taxpayers supporting the education of foreign students, especially those from countries with which we have poor trade balances.[13]

A peculiar aspect of this topic emerges when it is considered in relation to the gender composition of the labor force.[14] Consider what I will call "the scutwork hypothesis." It derives from the traditional American solution of securing workers for undesirable dead-end jobs--such as stoop labor and nursing sick people. the solution is to give the jobs to women or--if that does not work--to aliens. At about the beginning of the 1970s, American males evidently began to define the labors of doctoral engineers, or perhaps just of graduate students, as scutwork and began to abandon this career ladder in droves. The hypothesis suggests that efforts should then have been made to recruit women in graduate work, and evidently this was tried, but with insuffi-

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[13] Such views were expressed at the Workshop on the International Exchange and Movement of Engineers, National Academy of Sciences, Washington, D.C., July 7, 1987. Whatever the basis for these views, discussion at the workshop made it abundantly clear that the American economy has become dependent in important ways on the foreign engineering work force.

[14] In fact, gender and citizenship are seldom considered simultaneously. At the CIEME workshop mentioned above, not a single reference to gender was made throughout the day.

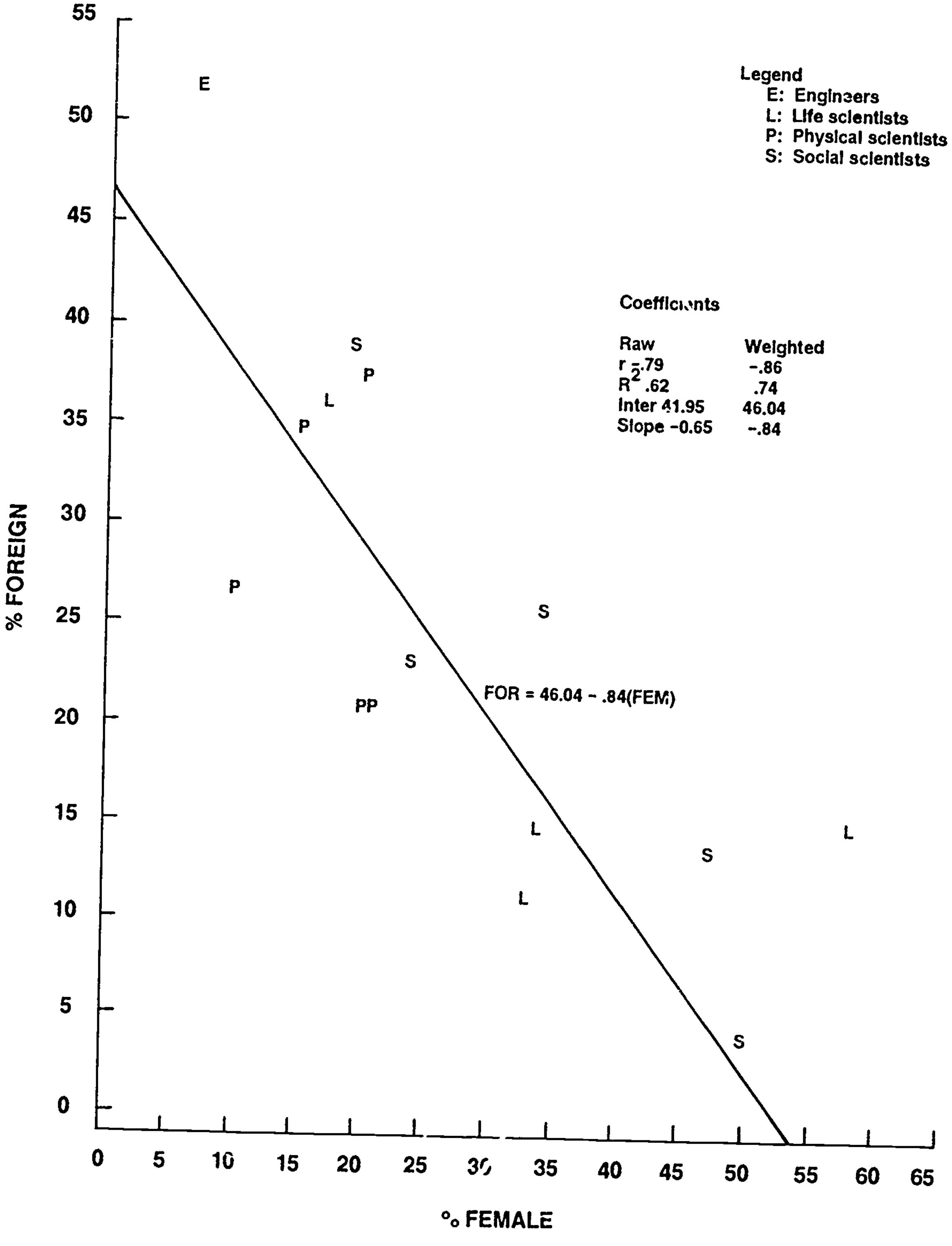

Figure 2. Foreign and female doctorate recipients from U.S. universities, 1984 (in percent, with regression coefficients).

cient success to fill the gap. The hypothesis predicts that this failure would create opportunities for foreign students to move onto and up this ladder which, as we have seen, was the case. More quantitatively, the hypothesis predicts that the larger the fraction of women in a field of S/E, the smaller should be the foreign fraction--that is, that the correlation between the two percentages should be large and negative. I have tested the hypotheses on 1984 doctorate recipients from U.S. universities (using data from the National Research Council's Doctorate Records File). The results are shown in Figure 2. The reported coefficients were weighted by total doctorate degrees awarded in each field that year. The data appear to support the hypothesis.[15]

Implications for Labor-Market Adjustments

If I am shown the results of the several labor-force projection models in S/E and am asked whether there are likely to be shortages in any of the fields of engineering, then I can only shrug my shoulders and say, "I don't know." Hansen's two thorough critiques of these models (1984, 1986) have convinced me that the models, although moving in just the right direction, have not yet provided definitive results. If I am asked the same question following this review of the demographics of engineers, I would answer, "You bet that I do." However, my answer would be less concerned with the fields than with certain demographic sectors. In particular, I suggest that CEIMA should be concerned about the field in toto--and still more concerned about female and doctoral engineers and about some critical missing information.

Here is how I reach the first of these conclusion: NSF's *National Overview* (1985c) provides counts of new entrants with at least a baccalaureate degree in 1982 to the fields of S/E (Table B-8) and of the size of the labor force in these fields in 1983 (Table B-2). By computing ratios of new entrants to the labor force on a field-specific basis, we obtain crude measures of the "replacement rate"[16] that focuses our attention on numbers of new entrants required for replacement of losses to a field from attrition and the residual numbers that are available for growth. As computed, the measure ignores new entrants with less than a B.S. degree as well as the effects of net occupational migration.[17] To assess these rates with any wisdom also

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[15] At least one alternative hypothesis could account for the data: the "harder" a field in its mathematical requirements, the more foreign citizens and the fewer females it attracts.

[16] "Replacement rates" refers to new entrants into the work force who (1) have a baccalaureate or higher degree and (2) are employed in S/E occupations. This represents 56.1 of employed new entrants in science, but 88.6 percent of employed engineers. The labor counts used in the denominators of the replacement rates include all those employed in S/E occupations without regard to education (NSF, 1985c, Tables B-1 and B-8).

requires the missing informational link: accurate counts of field-specific attrition. I think that this replacement measure, even with these warts, provides useful information.

In 1983, the replacement rate for all scientists was 8.5 percent. Even if attrition operated at 3 percent that year and demand grew by 5 percent, the market for scientists would be a bit soft. In the physical sciences and in computer specialties, it was about 5 percent, a good bit tighter. In engineering it was just under 3.4 percent. Only two fields were substantially below this gross rate: astronautical/aeronautical (1.2) and "other" (2.6). I *think* these rates are cause for some concern and certainly for further study, but then I do not really know, nor does any of us, because we do not know how the force of attrition operated that year. And even if we did, the information would give us a poor base, at best, for projecting the future. In light of recent changes in legislation about mandatory retirement and the possibility of changing plans for retirement, accurate projections become yet more difficult.

Women engineers always have been and continue to be grossly underrepresented in the labor force--in at least 3 of the 12 meanings of "gross" in my dictionary. Their growth rates are healthy, but not nearly large enough to make them a major component of the engineering labor force in this century. My sense is that there is relatively little potential for growth in the numbers of male U.S. citizens in engineering. To the extent that this is correct, then we must rely much more heavily on females and foreign citizens for the supply of new engineers to meet increases in demand.

My concern about doctoral engineers is that they--at least those in education--are the key element in labor-market adjustments and their situation is not healthy. In 1983 they numbered about 61,800--of whom only about 20,300, or about one-third, were in the educational sector (NSF, 1985c, Table B-5). This contrasts vividly with the 64.8 percent of doctoral scientists who are academically employed. The replacement rate of doctoral engineers in 1983 was 6.8 percent, better than that for engineers overall, but hardly representing an oversupply. An important problem here is that the fraction of these doctorate holders who are employed in academe has been shrinking for at least the past decade: down from 36 percent in 1973 to 32.8 percent in 1983. Since I am convinced that the quality of training bears at least a slight negative relationship to student/faculty ratios, I am also convinced that we are coming to a point where our colleges and universities will produce fewer or poorer engineering graduates.[18]

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[17] Between 1972 and 1978, there was a net loss of about 20 percent of engineers through occupational migration with an average annual loss of 3.7 percent (NSF, 1985c, Table B-34). Moves to administration accounted for the bulk of the loss. Exit from the S/E labor force occurred at an average annual rate of about 1 percent.

[18] For a lively discussion of the "crisis" in engineering education, see National Research Council (1984, pp. 113-122). For a survey of the views of academic chairpersons about the quality of foreign academics in engineering, see Barber and Morgan (1987).

One final point needs to be raised in this sociological analysis of the engineering labor market. It has to do with geography and the friction of distance. In practical terms it comes down to this: is the labor market for engineers national, or is it rather regional? The supply/demand models assume predominantly that it is national, that a new entrant from Seattle is as likely to fill a vacancy in Los Angeles as is one from Maine. Sociologists and geographers, on the other hand, have made clear the fact that, among movers, short moves are much more likely than long ones. This friction of distance is also known to be reduced by level of education (Ladinsky, 1967). But even among the most highly educated scientists, there is evidence that moves tend to be more regional than national (Hargens, 1969). This suggests to me that the projection models and our concerns about labor-market adjustments need to be disaggregated in still another way: by geographic region.

Performance Evaluation

This final section will be brief for the simple reason that I have little to say about the topic except from the perspective of the sociology of science. To say anything at all about performance evaluation, it is necessary first to consider several aspects of the process. In particular, we need to know whose performance is being evaluated: is it that of an individual, a production unit, an industry, or the national economy? To consider the units of evaluation requires us also to consider the criteria and purposes of the process. Since criteria, and possibly even the purposes, of performance evaluation must vary sharply across sectors and types of work activity, I will consider them only within certain of these categories.

Units of Performance Evaluation

The evaluation of on-the-job performances of individual workers is so ubiquitous and frequent an activity throughout the U.S. economy that libraries now bulge with "how to do it" books on the subject.[19] The purposes of such activities are fairly clear: to provide a basis for distributing rewards (and punishments) for performance and for evaluating incentive plans and needs for retraining in order to improve performance. These purposes certainly touch on those of CEIMA as discussed in the introduction to this paper, but their levels of concern may be too microscopic for our purposes. Certainly the assumptions laid out in the introduction stress individual characteristics: qualifications of workers, their match to positions occupied, and the quality of their individual performances. It is important that the nation be able to assess the level of mismatching between workers and posi-

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[19] For what appears to be a typical example of this literature, see Globerson (1985). For a focused look at aging and obsolescence in this context, see the volume edited by S. S. Dubin, *et al.*, 1974.

tions in its high-technology occupations, but it cannot today because of inadequate taxonomies and insufficient research. But other units need similar attention, particularly that of the productive organization.

To the extent that the issue before us is the impact of the available supply of engineers on productivity, then the focus of our attention ought also to be on mixes of engineers in organizations in terms of fields and levels of training, years of experience, and how such mixes affect productivity. Research at this level could also tell us a good deal about other characteristics that probably are closely related to productivity, such as fungibilities within given mixes of engineers and the ability to retain workers.

Academic Performance in Engineering

In the sociology of science, performance evaluation is a central problem, and performance is well understood to mean the advancement of knowledge through the publication of research results. A correlative problem is to assess the "impacts"—some call it the "quality" of the product—as measured by citations in the scientific literature to published articles. In this perspective the predominant unit of analyses is aggregates of individuals with common characteristics, such as winning a Nobel prize or being on the faculty of a leading research university.

This perspective is of relatively little value in performance evaluation of engineers, however, since only about 5 percent of them report basic or applied research as a primary work activity. Nonetheless, analyses of publications and citations remain the chief mechanisms for assessing the collective research performance of academic engineering in the larger research institutions.

As a tool for evaluating individual performances, publication and citation counting is extremely dangerous and usually ill-advised. Publication and citation frequencies vary drastically across fields and specialty areas of S/E, as do journal rejection rates. Thus, uses of these indicators of research productivity should be applied to relatively homogeneous entities, such as in historical studies of the development of a single field of engineering, or in analyses of larger units, such as colleges of engineering in which disparities of publishing and citation rates would likely cancel out.[20]

In any evaluation of academic engineering, the educational function deserves at least as close attention as does that of research. There are several lines of needed research on this topic. Those to

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[20] We do not know a great deal about the publication and citation patterns of engineers, but what is known suggests that there are some striking differences from those in science. For example, there is a greater propensity among engineers than scientists to refer to books (especially handbooks) rather than to journal articles. The three articles most highly cited in engineering journals in 1973 all concerned computing algorithms (Garfield, 1977).

which I would assign the highest priority concern career outcomes of graduates. One line of investigation should focus on questions such as whether there are systematic differences in the careers of graduates of different types of institution--differences in sector of employment, performance evaluation, promotion rate, and other job characteristics. A second line that I recommend is closely related to the first. It concerns what is coming to be called the "productivity of academic departments that grant baccalaureate degrees." The indicator of productivity of an academic unit (usually a college) is the fraction of that unit's bachelor's degree recipients in some period of time who go on to receive doctorate degrees in some later period. The National Research Council provided such data at the college level for 1984 doctorate recipients (Syverson and Coyle, 1986, Table L). The California Institute of Technology was the most productive institution in the nation that year. This indicator could be applied usefully at the levels of engineering schools and of individual departments. This could be implemented simply with the Research Council's Doctorate Records File and could provide the basis for research into the determinants of levels of productivity.

CONCLUSIONS AND RECOMMENDATIONS

My main conclusion is this: the demographic composition and trends of the engineering labor force are peculiar and, in some respects, problematic when compared with those of the sister profession of science. I believe that some of these characteristics have implications for labor-market adjustments, and possibly for the quality of performance, while others represent forces of adjustment that are already in play. My main nonconclusion concerns the risks of important shortages and consequent requirements for market adjustments resulting from spurts in demand. The projection models fail to convince me one way or another. Even here there is an important exception.

If we assume that demand remains sufficient to require over the next couple of decades an engineering labor force at least as large as it is today, then some market adjustments will be called for.[21] New entrants into the labor force are nearing the point of failing to match losses from attrition. The imbalance results less from a decline in new entrants (which is not the case) than from the rapid aging of the labor force. I am also convinced that acute shortages exist today in certain demographic sectors of the engineering work force. From the perspective of equity, there is a drastic shortage of women and most minorities (Asians are a conspicuous exception). There is also a serious shortage of engineers with doctorate degrees in the academic sector. Finally, I am convinced that we lack information that is essential to evaluating alternative market adjustments and their implications for productivity and quality.

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[21] Even this conservative assumption merits careful examination. There is anecdc , evidence that some large industrial employers plan to reduce the number of engineers whom they employ.

In light of these conclusions, I recommend that a thorough assessment of what we know about engineers be undertaken and, where needed, that a program of research be implemented that includes the following components:

- Skills: On the demand side we need to know both about the specific mathematical, computing, materials, design, and related skills required by occupations with distinct job titles and about equivalence classes of jobs. On the supply side, we need to know which skills derive from given levels of education in each field of S/E and what additional skills derive from a given number of years of experience in each class of jobs. This information is essential to useful analyses of labor-market shortages, feasible adjustments, and implications for performance.
- Aging: Because this is such an important characteristic of the engineering work force, we need to know its implications for both performance and attrition. There is a fair amount of conventional wisdom about the number of years on the job prior to "burn out" in some fields such as computer specialties. Does performance capability vary with age? The same conventional wisdom has been applied to some fields of science such as physics and mathematics, but sociologists of science have been able to find no strong supporting evidence. How changes in retirement legislation affect retirement plans is an important piece of information for labor-force projections.[22] I believe that we do not have this information today.
- Recruitment: For both equity and sound labor-force policy, we must better understand the mechanisms by which women and minorities are recruited into engineering education and, subsequently, the work force. These mechanisms need to be harnessed in order to bring about better proportional representation, regardless of the needed size of the total work force. If credible signals of long-term shortage emerge, then women—together with foreign citizens—are probably the best sources of rapid growth through the academic pipeline. A special case of the need to understand recruitment patterns into engineering is that of recruitment into candidacy for the doctorate degree. I have argued that these patterns are particularly problematic and in need of careful study.
- Retention: In addition to losses from attrition, the S/E labor force undergoes losses as a result of failure

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[22] A study of aging in science is under way in the National Research Council.

to retain qualified workers in appropriate positions. Engineers are efficiently employed relative to most disciplines of science, but there is still a substantial slippage. About 15 percent of employed engineers in 1982 were not employed in S/E positions (NSF, 1984b, Tables B-1 and B-12). In that same year nearly 20 percent of new entrants, exclusive of full-time graduate students, were out of S/E (NSF, 1985c, Table B-8). This may or may not represent a substantial reserve force in case of sudden national need. It is important to know the conditions that would be sufficient to draw them back into engineering employment, should the need arise.

- Quality: I have discussed quality indicators in academic engineering, at the level both of individual faculty members and of departments or colleges. Other committee members will presumably suggest appropriate indicators at various analytic levels in other sectors on which the committee can reach consensus. This done, it should be possible to obtain measures of them and, of critical importance, to determine what factors account for variance in them. I have suggested that skill matches and mismatches may prove to be an important factor so that the first line of research suggested above might be carried out in conjunction with investigations of performance quality. I believe that it is important to consider not merely quality of product, but quality of the work environment as well. Job satisfaction should clearly prove to be a determinant of the ability to retain engineers in appropriate positions. This may be an especially important consideration in the case of women and minorities who, because of their paucity in the field, may have ties both to the profession and to their jobs that are fragile and tenuous.

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CHANGES IN ENGINEERING QUALITY AND PERFORMANCE: POTENTIAL INDICATORS OF ADJUSTMENT

Alan L. Porter
Georgia Institute of Technology

INTRODUCTION

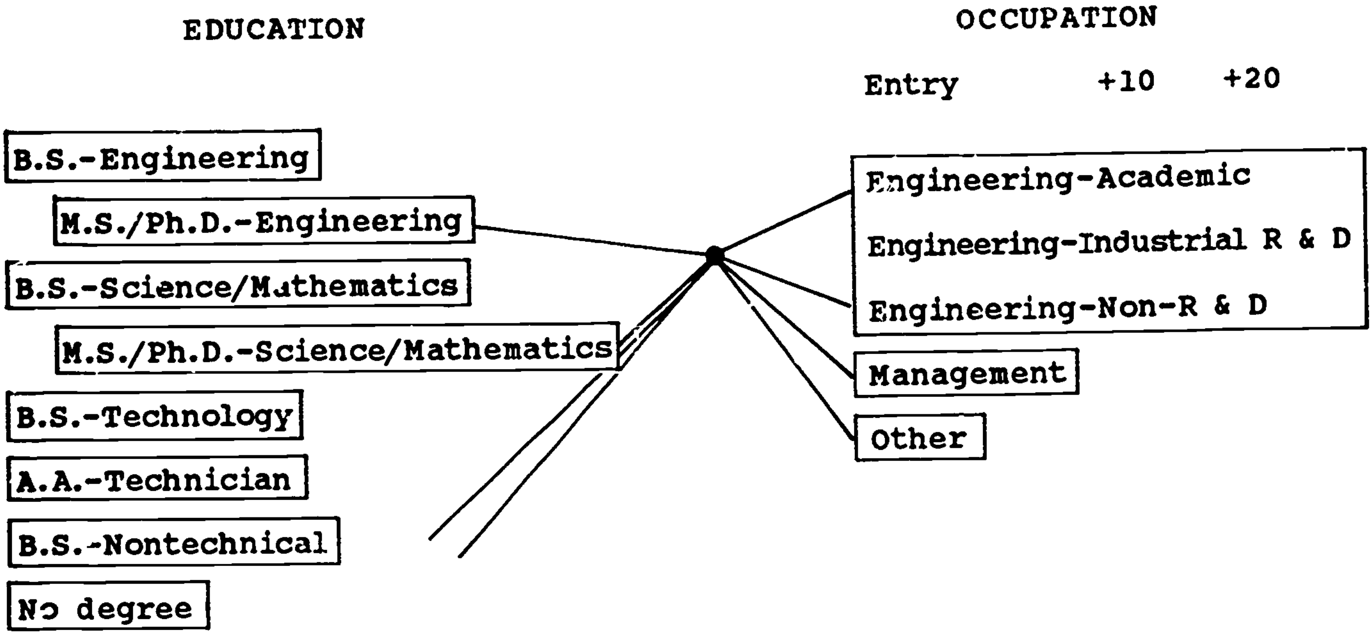
Changing market conditions for engineers could affect the quality of personnel filling engineering positions in academe, industrial research and development (R&D), and other industrial jobs. This paper considers how such effects could be measured. It draws on research from several related traditions: industrial psychology, organizational behavior, engineering management, and R&D management. The paper is organized in three sections:

- Consideration of "inputs"--that is, quality of engineers;
- Consideration of "outputs"--that is, engineering performance; and
- Discussion and recommendations.

The paper does not comprehensively cover the various literatures; rather, it seeks to raise critical issues and offer practical possibilities to study the impacts of engineering demand changes.

QUALITY OF ENGINEERS

Quality implies capability. Many factors contribute to engineering capability--intelligence, motivation, experience, education. One might worry about the intellectual capability of American engineers drawn from a population with IQ scores some 10 points lower than the Japanese population, a phenomenon seemingly attributable in large part to cumulative educational effort (Barber and Morgan, 1987). In terms of motivation, perhaps our affluent culture has eroded the "work ethic" so as to handicap American engineering. One could imagine devising skill tests specific to certain engineering job requirements in search of "quality," but that seems outside the scope of present efforts. Another possible quality indicator is certification--the Professional Engineer (P.E.). However, that is primarily relevant only to certain disciplines such as civil engineering, wherein the engineer takes individual responsibility for a design. So, it seems sensible to concentrate on education and experience as indicators of quality.



NOTE: The horizontal dimension aims to suggest movement over time.

Figure 1. Multiple education-occupation paths.

Figure 1 offers a model of the "flow of engineers." Inherent in this model, as in most thinking about quality, is the notion that formal educational credentials are critical. As presented, the model begins with education (degrees received), then tracks the diffusion of the degree recipients across occupational groupings of interest. (There is no reason that individuals could not continue their education while progressing through their occupational careers.) Tracking individuals, as they gain experience and change jobs, is implied by the time dimension shown for occupation. In finer grain, capabilities change as individuals learn new tasks and acquire specific skills using new technologies.

The model suggests several questions regarding engineering quality. One concerns the diffusion of engineering graduates out of engineering jobs. In the early 1970s, for instance, the aerospace contraction led to highly technically trained stockbrokers and used-car salespeople. This paper focuses on the complementary issue, instead--the diffusion of those not formally credentialed in engineering into engineering jobs during periods of high demand for engineers. As suggested by the model, such inflow can take various forms:

- Formal retraining, wherein those with technical backgrounds obtain engineering degrees (e.g., Georgia Tech had math doctorates taking M.S. degrees in engineering a few years back).
- Special programs, wherein those with technical backgrounds are "retreaded" for engineering work through shorter certificate programs (e.g., a University of Dayton program in the 1970s).
- On-the-job experience to convert those with science or math backgrounds into working engineers, without formal training.
- On-the-job experience to convert those with "subordinate" technology or technologist degrees, or those without formal technical training, to practicing engineers.

Presumably, quality concerns are not paramount with the first two categories, although distributional concerns may arise (e.g., if demand for engineers were to induce a shortage of scientists in some domains, or if industrial pull were to induce academic shortages). One might, however, investigate whether differences between scientists and engineers in terms of working styles, career orientation, and skills (see, for example, Allen, 1977) reflect on engineering quality when scientists switch to engineering. Many variations of the latter two, experiential categories are possible and constitute the domain of quality concerns on which I focus.

National statistics are essential to ascertain the magnitude of the quality issue, or even if an issue now exists. I suggest compilation of U.S. data to construct a flow model, based on Figure 1, analogous to the Department of Energy flow models that show the mix of U.S. energy sources and uses in the 1970s. Presumably, both education (degrees conferred) data and occupational data relevant to engineering are available, but <u>linking</u> these might not be easy. Linkages might be approximated from small sample and partial results. That is, evidence on the numbers in certain engineering disciplines who have shifted fields might allow one to estimate the numbers of nondegreed engineers who must be making up the difference to fill the engineering jobs. Another possible concern is the substitution of foreign nationals, especially those trained in less developed national systems, in American engineering jobs. The influx of foreign nationals as graduate students in engineering in the United States is an issue receiving much attention.

Technician (under 4-year) and technologist (4-year) degrees deserve special attention. Statistics on these are notoriously unsatisfactory. The National Science Foundation (NSF, 1982) reports about 1 million total science- and engineering-related technicians in 1980, yet annual graduation at 200,000. What happens to them? Technologists are not reported separately, implying that the quality distinctions between them and engineers present in their educational credentials may be ignored by employers.

National statistics also permit cross-national comparisons. The relative and absolute numbers of engineers trained in the Soviet Union and Japan outdistance those of the United States (National Science Board, 1985:192). Comparison in terms of the distribution of degrees by engineering disciplines and the nature of subordinate training of technologists, for example, might provide more insights. Further analyses of occupational statistics would be of interest to compare key industrialized nations in terms of:

- Distribution (i.e., industrial versus academic employment of engineers; R&D versus non-R&D employment; defense-related versus civilian employment; sectoral differences in engineering employment);
- Concentration (i.e., engineers per total employees; engineers per value-added in various sectors); and
- Temporal characteristics (i.e., how stable patterns are over time; how quickly various systems respond to changing demands).

Ideally, such statistics would be augmented with country expertise to illuminate the causes and consequences of any observed differences. For instance, a Chinese R&D manager conveyed his quality concerns occasioned by a system in which "everyone eats from one big pot"—that is, anyone, no matter what his or her training, is eligible for an engineering job opening, leading sometimes to political criteria substituting for technical criteria in filling positions.

Comparative statistics, within the United States and cross-nationally, would be of interest regarding rates of crossover between specializations. Our small sample studies have found that even Ph.D.s change fields of specialization quite rapidly (Porter, *et al.*, 1981; 1982). It would be informative to know to what extent engineers evolve new areas of substantive expertise and new technical skills as a function of time post-degree (Porter and Rossini, 1984). Impressionistic reports suggest increasing numbers may work on multidisciplinary teams. That may diminish the importance of specific degrees as an indicator of quality, in favor of flexibility, communication skills,

TABLE 1: Technologists, Technicians, and Managers, by Educational Groups (in percent)

Graduates	72	6	16	7	100	8,425
Professionals	67	11	13	8	100	5,965
HNCs	41	32	16	12	100	14,695
ONCs	[illegible]	46	12	27	100	14,203

	Managerial Group						
	Top	Sr	Mid	Jr	Foremen	Other or Not known	All Managerial Groups
Graduates	4	6	13	18	—	58	100
Professionals	3	9	18	20	2	47	100
HNCs *	1	2	10	16	2	69	100
ONCs *	—	1	4	10	3	81	100

*Undifferentiated.

NOTE: Graduates include those with university degrees in engineering, mathematics, or science; professionals, other than degree holders, are members of engineering professional institutions; HNCs are those holding a Higher National Certificate in engineering; ONCs typically follow a route of part-time study to obtain an Ordinary National Certificate.

SOURCE: P. R. G. Layard, J. D. Sargan, M. E. Ager, and D. J. Jones, *Qualified Manpower and Economic Performance: An Interplant Study in the Electrical Engineering Industry*, London: The Penguin Press, 1971.

broad interests, and so forth. This appears especially true in engineering design, with increasing emphasis on integration with manufacturing, maintenance, and marketing (see, for example, Anonymous, 1984).

A study by Layard, *et al.*, (1971) provides a good prototype of small sample data. This cross-sectional study of 68 British factories examined the relationship between electrical engineering training and jobs. Table 1 reproduces key sets of findings, demonstrating a significant intermixing of the educational groups in both technical positions and management responsibilities. "Graduates" include those with university degrees (in engineering, math, or science); "professionals" are members of electrical, mechanical, or other engineering professional institutions, other than degree holders (they hold national diplomas based on full-time study, too); "ONCs" typically follow a route of part-time study for 2 to 3 years to obtain an Ordinary National Certificate (ONC); "HNCs" go an additional 2 years for a Higher

National Certificate (HNC) in electrical, mechanical or other engineering.

The findings from Layard *et al.* suggest the possibility of quality concerns pertaining to training vis-a-vis engineering job responsibilities, but they refrain from recommending educational requirements. They consider a production function model, seeking what might be a desirable ratio of engineers to total employees (a ratio widely variable in their sample) as one contributor to a productive manufacturing operation. They conclude that the productivity of engineers depends on all other variables in the production function as well (e.g., capital-intensity, products involved--some being more sensitive to skilled engineering than others). The method of manufacture (Woodward, 1965) and scale of the enterprises are also found to be pertinent. Their economic analysis finds, for their sample, no evidence of a shortage of engineers in industry (based on rate of return for an individual obtaining first and advanced degrees). They also note that the causes of observed salary differentials by educational group are confounded--ability with education (they pursue certain analyses varying the proportion attributed to education from 50 to 100 percent).

This discussion of quality has focused on educational credentials and experience. The trade-off between these is complex--some jobs depend more heavily on experience; others, on advanced training. I have emphasized general engineering quality concerns over those specific to academics and engineers in R&D. The latter tend to involve persons with advanced degrees, which to some extent attest to quality. One could certainly compare nations or sectors in terms of quality measures such as percent with doctorates. Shortages could be estimated by tracking salaries over time, rise in percentage of non-U.S. nationals hired, and so on. On balance, however, it seems to me that the key quality issue is whether there is a demonstrable link between educational attainment and occupational performance. I believe resolution of this linkage issue requires small sample studies to complement the difficult-to-relate national statistics on engineering education and engineering employment.

ENGINEERING PERFORMANCE

Individual work performance is determined by multiple factors--individual characteristics as well as situational characteristics (Landy and Farr, 1983). For example, studies have amply demonstrated that performance depends on work context (see, for example, Brass, 1981). Task complexity affects engineering performance, but it interacts with time in position and depends on whether the job is R&D (Kozlowski and Hults, 1986).

Figure 2 extends the notion to specify a number of factors pertinent to modern-day engineering performance. The underlying reality is certainly more complex than shown (e.g., training must be effectively linked with technology), but the point of the figure is to caution against a singular "quality leads to effective performance" image. Indeed, it is interesting to reflect on how easily one can narrow down to

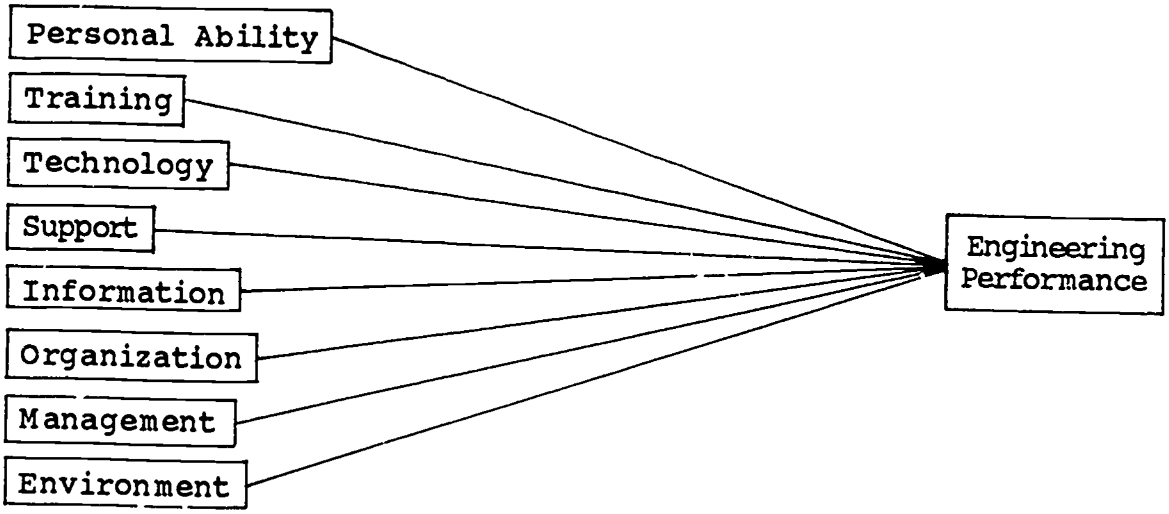


Figure 2. Multiple influences on engineering performance.

alternative singular causation models. National policymaking, at times, seems to blame unfair competitors (the environment) for perceived poor U.S. performance. Then again, we turn on management as the source of our failings. Or Japanese-style organization, favoring integration over specialization, is offered as a popular cure-all. Our Chinese colleague who manages R&D frets over the lack of suitable support for scientists and engineers in China compared to that available in the United States (Jin, *et al.*, 1987). Our present concern is to understand the roles of the first two factors--personnel ability and training--as contributors to engineering performance. It would be nice to add the phrase, "all else equal," to this, but that would be foolish in the present transition into the information age with rapidly changing engineering technology and organizational repercussions thereof. Indeed, recent Industrial Research Institute findings indicate that scientists and engineers in industrial R&D have just crossed a notable threshold: over half now routinely use computers (Rossini, *et al.*, 1987).

"Performance measurement" calls forth a host of generic issues. Smith (1976:749) presents a helpful three-dimensional framework for classifying performance measures:

- Specificity (from one aspect of job performance to an overall index);
- Temporal span (immediate to long term); and
- Link to organizational goals (from personal assessment to organizational effectiveness).

Most performance measurement aims to assess the individual (e.g., for annual raises or promotion); hence, many of the measurement issues are not of great moment to our policy-oriented appraisal of "national engineering" performance. Nonetheless, it is appropriate to note briefly a number of concerns:

- Validation of performance constructs (e.g., use of multitrait/multimethod approaches as per Campbell and Fiske, 1959);
- Psychometric criteria, such as accuracy and reliability (see, for example, Landy and Farr, 1983);
- Practicality (data availability at reasonable cost and on a timely basis); and
- Utility (credibility of measures, understandability).

Any measures proposed ought to meet reasonable standards on each of these counts.

Certain concerns (e.g., variability, reliability) that are extreme in the case of individual performance measures may be less severe on an aggregate basis, as pertains to the focus of this study. An issue of some importance for this study is whether to use measures of central tendency (e.g., mean or median performance) versus measures of dispersion (e.g., standard deviation or interquartile range). Would lowered quality of certain persons in engineering jobs be greatest, and/or of most concern, in terms of average performance or dispersion of performance of some target group? Gilbert's (1978) "potential for improving performance" (PIP) competence measure is determined by the ratio of exemplary to typical performance. Were one to find a group of engineers showing high PIPs (high variance), presumably this would reflect a quality problem. I would suggest both measures of central tendency and dispersion be gathered, as feasible.

Given this lengthy preamble, what should one use to measure "engineering performance"? Performance measures for research-oriented scientists and engineers include papers published, patents, citations, and peer judgment awards. Unfortunately, publication is far more pertinent to scientists than engineers (Allen, 1977), and measures such as patents fit R&D engineering better in some industrial sectors and some engineering disciplines than in others. Further interfering with most of these measures are industry's proprietary concerns that may discourage publication, and even patenting, in certain areas. Difficulties in differentiating individual contributions to team performance accentuate problems in comparing the performance of different quality research engineers. Making performance measurement even more troublesome, even Ph.D.s in electrical engineering, 10 years after completion of their doctorates, average only 25 percent of their time in research activities (Porter, *et al.*, 1982)--so research-only measures are not adequate gauges of performance, even for academic or industrial R&D engineers. [Furthermore, considerable evidence shows that "R" activities differ substantially from "D" (Leifer and Triscari, 1987).]

What performance measures could be used to get beyond research activities? The traditional performance measurement tool of supervisor ratings appears of little use to us. One might compare such ratings within organizational units between properly degreed and other personnel, but this would be difficult and costly, it seems. Were one to pursue such a route, an interesting alternative to simple ratings is to

TABLE 2: Baseline Composite Work Profile Matrix (in percent)

Employee Class	Higher-Value Work			Lower- & No-Value Work		
	Mgt & Supv	Spec Prof	Rout Prof	Admin & Support	Clerl	Non-prod
Managers	30	16	13	16	7	18
Senior professionals	2	35	26	13	12	12
Junior professionals	1	10	50	13	14	12
Administrators and technicians	0	0	1	58	27	14
Secretaries	0	0	0	10	76	14

NOTE: N = 587, four departments.
SOURCE: P. G. Sassone and A. P. Schwartz, Cost-Justifying OA, *Datamation* 32:83-88, February 1986.

obtain estimates of the value to the organization of the target individual(s) in terms of dollars per year (Landy and Farr, 1983). Recalling Smith's three-dimensional framework, our concerns should emphasize general (rather than task-specific), long-term performance in terms of value to the organization. Gilbert thinks of value in terms of quality, quantity, and/or cost comparisons.

Sassone and Schwartz (1986) offer an appealing approach to measure the productivity changes when one introduces office automation for professionals. Their "work profiling" approach is usable from cost justification through performance evaluation. The core idea is to differentiate tasks performed according to the skills required, recognizing that a given worker engages in varied levels of skilled activity. For instance, a senior engineer might perform certain activities requiring advanced engineering skills, some others demanding only routine engineering talents, and still others clerical or supportive in nature (e.g., proofreading, photocopying, driving to a meeting). Sassone and Schwartz typically identify some 15 to 25 work activities in a department and classify these into 4 to 6 main worker categories (managers, senior professionals, junior professionals, technicians, secretaries). They find, in general, that professionals (and managers) spend only about 61 percent of their time on higher valued activities, the rest going to support/clerical work and waste time (see Table 2). Productivity gains are measured in terms of shifting time spent toward higher valued activities. Implicit dollar values are attached to each level of activity according to salary structure and baseline time allocations. So, if office automation results in the professional increasing the time allocated to specialized professional tasks from 35 to 40 percent, this translates into a monetary gain.

To resolve the concerns about how quality relates to the performance of engineers, one must know what different quality engineers do.

Work profiling offers the best vehicle of which I am aware to accomplish this. Work profiling studies could provide information pertinent to:

- The extent to which less qualified engineers perform higher-qualified work, and
- The extent to which less qualified engineers do similar or different work than higher qualified engineers.

A reasonable null hypothesis is that a department may hire engineers with differing quality credentials and have them do work commensurate with their capabilities. Indeed, one could imagine a work profile over time in which less qualified individuals gain on-the-job or continuing educational training and move their work profiles correspondingly upward over time. Such a situation would tend to dismiss engineering quality concerns. Any conclusion that uncredentialed engineers detract from engineering performance must be based on firm evidence that they are performing higher skill activities, and doing so less well. Layard, *et al.* (1971), refused to draw this conclusion from their British study.

On the other hand, should work profiles show that less qualified engineers do perform activities beyond their capabilities, various remedial actions could be considered. Within an organizational unit, this might entail introducing computer-assisted design (CAD) technologies so that senior engineers could oversee more advanced engineering work. On a national level, it might suggest increased financial support or faculty inducements for those engineering programs whose graduates are in relatively short supply.

Work profiling, unfortunately, implies in-depth, on-site analysis. Small samples, chosen for generalizability, would need to be examined.

DISCUSSION AND RECOMMENDATIONS

A number of issues further complicate engineering quality and performance. Changing information technologies, in particular, are changing required capabilities. The tasks that make up particular jobs are changing; work patterns are shifting (e.g., integrated design teams); organizations are adjusting to these altered roles. In this rapidly shifting milieu, the definition of engineer is not constant. Thus, any attempt to restrict the practice of engineering with enhanced credential requirements would be extremely dangerous.

In this context of rapid change, technological obsolescence is heightened. As Morano and Deets (1986) point out, there are many routes to technical education, including various corporate training possibilities. Over time, they perceive a growing gap of technical knowledge from the moment of college graduation as engineers forget what they have learned and the state of the art pushes forward. Again, this implies avoiding undue emphasis on quality criteria based narrowly on college degrees.

Broadened roles for engineers are a popular theme today. Some suggest that industrial competitiveness would be well-served by moving more technically trained people into *management* positions. Some engineers are oriented toward solving technical puzzles; others, toward management. Interestingly, salaries for a sample of MIT graduates favored those oriented toward human, rather than technical, interests (Bailyn, 1980). Another appealing Japanese tactic is to move engineers into direct *production* responsibilities. With the advent of flexible manufacturing systems (FMS), computer-integrated manufacturing, and sundry forms of automated processing, there is good cause for such a strategy. A recent study of FMS in Japan identifies more engineers than production workers operating these facilities (Jaikumar, 1986). Such shifts in engineering roles suggest loosening, not tightening, engineering criteria, in my view. Also, studying engineering quality and performance will become even more problematic as roles smudge.

Engineering performance encompasses an ever-widening domain. The image of tallying publications and patents to determine performance is just too narrow and drifting farther off the mark—even for R&D-oriented engineers. Salary and promotion are also flawed indicators, as are supervisor ratings. I advocate consideration of performance in terms of general (rather than specific), long-term (rather than immediate), and organizational value (rather than individual attainment). Quality, quantity, and cost factors warrant measurement. How does one do this?

National statistics can identify apparent shortages of trained personnel, relative disparities among nations in degrees granted, and so forth. Particular attention should be paid to the technologist and technician graduates. In addition, data on the infusion of information technologies (e.g., personal computers, CAD, shared data bases) into the engineering workplace are needed. Comparisons among academic, R&D, and other engineering workplaces would help identify gaps, training needs, and so forth. These various national statistics may help rule out quality problems, as discussed previously relevant to the flow of credentialed professionals. They are not suitable to tie performance problems to quality problems.

I recommend small-sample survey mechanisms aimed at determining if links can be established between quality and performance deficits. Several possibilities—recruitment cohort tracking, personnel manager interviews, work profiling—deserve consideration, in my view. To stimulate discussion, I suggest a survey along the following lines. The focus should be on *recruitment into engineering positions* in a given year. A heterogeneous sample of organizational units should be selected to include academic, industrial R&D, and industrial non-R&D operations. These should also show diversity by sector represented and scale of operations involved, perhaps also by geographical region (all, of course, a function of study resources). The study should include, perhaps, three cohorts of persons hired into the target units (whether new or experienced hires, or within-company transfers)—for example, 1965, 1975, and 1985. A modest amount of data should be requested for a random sample of persons meeting the cohort definitions—for example, age, degrees, salary, and brief job description. This should be augmented by information on these factors for, say, each fifth year thereafter and on training received. Thus, for a 1965 cohort one would be able to assess career progression for 20 years (relative promotion and salary increase rates, and so forth). The most cost-effective way to conduct such a survey would be through personnel managers for the selected organizational units. The survey could, perhaps, be constructed to require only information available through these single sources. That implies one would not track the careers of employees who left the company (interpretation will have to address selection, as well as power, representativeness, and other topics). Nonetheless, I recommend defining a survey in terms of a recruitment cohort as the most efficient way to obtain "flow" information from education into occupation--and that is critical to make progress on the issue of whether quality is affecting engineering performance. The characteristics of persons being hired into engineering positions could be compared for 1965, 1975, and 1985. Attention would be directed to changes in the percentage with engineering degrees. The relative career progression of persons hired with different credentials could be tracked.

Such a survey should contribute significantly to resolving the key quality issues:

- Are significant numbers being hired into engineering positions without suitable credentials?
- If so, what are their backgrounds?
- Are there identifiable differences in their career progressions (an imperfect indicator of performance differences)?
- Do those with less desirable credentials perform similar work? (If their work entails less responsibility, perhaps there is no quality issue.)

Should such a survey not be feasible, I offer an alternative. I believe a 5-minute phone survey of, say, 50 personnel officers for suitable organizational units might be quite informative. A key question would be, "Is there, or has there been, difficulty in filling vacancies with qualified engineers?" If not, quality problems, in terms of educational credentials, are moot. If yes, it would be useful to distinguish these shortages by discipline, type of job, job setting, sector, and other areas. (Salary differentials between engineers and others--scientists, mathematicians, technologists, in particular--might be tracked over time as an indicator of relative demand.)

My third (and final) small-sample survey recommendation is to do "work profiling" for a few organizational units. These should, if possible, span R&D and non-R&D engineering. They definitely should include adequate numbers of practicing engineers (1) with technician training, (2) with technologist training, and (3) with bachelor's degrees in technical areas other than engineering degrees. The key interest is to identify who does what sorts of work. Again, this information would be vital to identify a quality-performance problem.

Should a case emerge that quality shortfalls are resulting in performance problems, appropriate remedial actions can be considered. It would seem that continuing education options--academic or industry-based--deserve priority consideration. The continuing education requirements of the health and education professions offer a model for consideration.

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THE IMPACT OF ADVANCED MANUFACTURING TECHNOLOGY ON THE EFFECTIVE UTILIZATION OF ENGINEERS

Gerald I. Susman
The Pennsylvania State University

INTRODUCTION

The quality of the American engineering work force is as important to our prospects for achieving competitive success as is the supply of engineers. Attempts to assess quality are usually made by looking only at the attributes of engineers--such as years of schooling and number and types of degree. Such assessments, by themselves, are of limited value unless judged against competitive opportunities that require high-quality engineering. Just as assessments of engineering quality cannot be made in absolute terms, neither can prescriptions be made for how to improve quality without considering the available technologies and practices that engineers might use in the future.

Several types of advanced manufacturing technology, developed recently, have the potential to improve the productivity of engineers as well as to upgrade their knowledge and skills. However, these new technologies will not realize their full potential unless they are introduced with complementary organizational changes. These changes can lead to using the existing engineering work force for higher value-added activities than is the case currently. Advanced manufacturing technology may have a greater impact on U.S. competitiveness by changing the way the existing engineering work force is used than by increasing the efficiency with which engineers perform the work they are currently assigned.

RELATIONSHIP BETWEEN THE DEMAND FOR ENGINEERS AND THE QUALITY OF THE SUPPLY

Management can meet its demand for engineers even when it is faced with an uncertain supply (National Research Council, 1986). However, the mechanisms that it uses to meet its needs are short-term responses, which may have long-term negative effects on the quality of the supply. These short-term responses include (a) substituting technicians for engineers, (b) importing foreign engineers or encouraging those working or studying in the United States to remain here, (c) discouraging engineers from taking managerial or nonengineering positions (e.g., in sales). When management's demand for engineers weakens, it is likely to do all of the above in reverse as well as to reduce spending on research and development (R&D), to lay off engineers and technicians, and to assign the engineers whom it retains to technical or nonengineering jobs.

The uncertainty of supply arises because management ties the extent to which it uses engineers to the peaks and troughs of the business cycle, rather than using engineers to pursue long-term competitive advantage in foreign and domestic markets. Its short-term responses to shifts in the business cycle have a long-term impact on the quantity and quality of the supply of engineers. When demand is weak, fewer students enter engineering schools. As the typical student takes 4 years to complete an engineering degree program, there is generally a lag in supply when demand strengthens. This encourages management to rely on the short-term responses that created the lag in the first place. Also, laying off engineers and shifting them back and forth between engineering and nonengineering jobs interrupt the continuity and familiarity that engineers have with the company's products and processes that are necessary for productive and effective problem-solving.

A solution to the supply problem created by wide swings in the demand for engineers is to encourage companies to utilize engineers more consistently in pursuit of strategic competitive objectives. Management would be more willing to invest in training engineers whom it utilizes more consistently, viewing them as appreciable assets. Engineering students and the universities that train them would be able to provide the needed supply in a more orderly fashion than is now the case.

American companies in some industries differ from their Japanese counterparts in their responses to business downturns. Kawasaki Steel, Nippon Kokan, and Kobe Steel either retained or increased their level R&D spending during the recent business downturn in Japan. In contrast, Bethlehem Steel cut its research spending in 1982, when it began to incur losses, and followed with further cuts in 1983 and 1984 (Yoder, 1987).

HOW CAN THE KNOWLEDGE AND SKILLS OF ENGINEERS BE BEST USED FOR COMPETITIVE ADVANTAGE?

An assessment of the quality of engineers should be made against the demands that can make the most difference in improving a firm's competitive advantage. The United States, Japan, and countries of Western Europe are finding greater profits in high value-added customized production than in low-cost standardized production. This shift leads to corresponding changes in the knowledge and skills required of engineers. Some of the means that firms can use to compete effectively in markets for customized products are discussed below.

Customer Focus

Interaction between engineering and marketing personnel, as well as between engineering personnel and customers, will assure the design of new products that meet customer tastes and needs and will sell in the market. The frequency of such interaction will increase as more American firms switch from producing standardized products to producing customized products. Advanced Micro Devices, for example, specializes in finding new uses and unmet needs in the memory- and logic-chip market. Potential customers look at preliminary chip designs and make suggestions for improvements (Schonberger, 1986). Compaq computer starts its product development cycle with a one-page product description. After top management approves it, Compaq sets up teams of manufacturing, marketing, and engineering personnel (Uttal, 1987). These teams assure that manufacturing can build the product more readily and that marketing will have an easier time selling it.

Continuous Product Improvement

Many firms will have to use continuous product improvement as a standard competitive strategy regardless of whether they are in a new or mature industry. In new industries such as computers, biotechnology, and pharmaceuticals, new products are being introduced rapidly. The underlying technological base of these products is being exploited, often with different approaches until an industry standard or consensus is reached. These products have only a short time to recover their costs before they are eclipsed by still newer products.

A company able to get its product to market faster than its competition can earn a premium price for its product and reduce any likelihood that competitors can clone it and sell it at a lower price. Also, it may be less risky and less costly in the long run to introduce frequent small improvements based on customers' reactions rather than to try to take one great leap forward. It is not uncommon for companies to have several generations of a product already planned by the time the initial product is introduced (Uttal, 1987).

Continuous Process Improvement

Japanese and German companies are more likely than American firms to have large, well-staffed manufacturing engineering departments that develop proprietary production processes rather than relying on independent suppliers to develop these processes. If continually given challenging assignments, company personnel can steadily improve productivity because of their intimate familiarity with the company's products and their personal relationships with people in other parts of the company (Hayes and Wheelwright, 1984).

TO WHAT PROCESS AND PRODUCTS SHOULD ENGINEERS APPLY THEIR KNOWLEDGE AND SKILLS?

An equally important aspect of applying engineering knowledge and skills to competitive advantage is applying them toward the most promising product and process technologies. An assessment of engineering quality would be incomplete without assessing the technologies to which engineers' knowledge and skills are being applied and the industries that have the greatest potential for exploiting these technologies. It is beyond the scope of this paper to be specific in exploring which technologies and industries are most promising. Some of the better-known examples, however, include composite materials for aircraft, fiber optics for telecommunications, and ceramics for automobile engines. Foster (1986) has recommended that firms study the "S curves" of the technologies that they use in their current and projected products. An S curve is a graph of the relationship between the research and development effort put into improving a product or process and the results obtained from that effort. Significant gains can be obtained from technologies that are at the start of their S curve, while relatively little can be obtained from those that are beyond the peak of their curve.

The following technologies not only can improve engineering productivity (with its supply-side implications) but, more importantly, can permit better use of existing engineering knowledge and skill. All of these technologies are software-intensive, and most are used when products are designed and manufacturing processes are planned. Consequently, they have high leverage for productivity improvement because they significantly influence "downstream" activities and costs. Other types of advanced manufacturing technology such as numerical control machines, robots, automated materials handling, and automated storage and retrieval systems (i.e., computer-aided manufacturing) are not discussed in this paper because their impact on engineering productivity is less than that of the other technologies discussed.

Although the productivity impact of each type of advanced manufacturing technology can be assessed separately, the most dramatic impact will occur when they are integrated to form computer-integrated manufacturing. The following technologies and their productivity impacts will be discussed separately, followed by a discussion of the likely impact of integrating them.

Computer-Aided Design and Engineering

There are many types of computer-aided design (CAD) and engineering (CAE). Most American companies use CAD in its most elementary form, as an "electronic drafting board" to create new designs. However, such electronic drafting can be very sophisticated, permitting designers to draft in two or three dimensions with "wireframe" or solid models. CAD used in this way can significantly reduce the time necessary to produce drawings and preliminary models. One major electronics firm found that 2 years after installation, CAD systems were two times as productive as manual systems in mechanical environments and four times as productive in electronic environments (Nolen, 1985).

The next step in sophistication for CAD is to transform drawings or models into "finite elements" so that the models can be analyzed for stress, function, and so forth on a monitoring screen. 3M cut 6 months off the 3 years it normally needs to develop a microfilm reader, because the model designed on a computer was good enough to go straight into production. With a more complicated product, an experimental heart pump, 3M saved 2 years of testing by simulating the surface to ensure that it would not make blood clot (Uttal, 1987).

Further savings in time and personnel are possible when design data are digitized. Expert systems (discussed below) can analyze design data and determine optimal methods for transforming the design into a product. These data then can be downloaded to post-processors that transform the data into tape or code that instructs machines about how to produce the product. A significant amount of technician time in the average company is currently devoted to translating product drawings into programs that instruct numerical control machines or robots about how to produce the product.

Expert Systems

Expert systems are applications of artificial intelligence to problems that are specific to a body of knowledge or domain of expertise. Some of these domains of expertise in manufacturing include the following: design, process and facilities planning, and maintenance and fault diagnosis.

Design

Sophisticated software such as that recently announced by Microelectronics & Computer Technology Corporation (an industry research consortium based in Austin, Texas) can sharply cut the time needed to design customized chips (Lubove and Duke, 1987).

Process and Facilities Planning

A very large number of expert-systems applications concern process and facilities planning. These systems use digitized design data to determine, among other functions, machining operations, tools, speeds and feeds, and operating sequences. Related software programs use similar types of information (e.g., material flow, safety, employee convenience) to decide on facilities layout.

Maintenance and Fault Diagnosis

The time needed to diagnose the causes of downtime on expensive automated equipment can be reduced significantly. Once the logic of diagnosis is captured, a company need not be dependent on the same few persons always being available when equipment breaks down. Also, as the data base is cumulative, the company is less susceptible to decay of its experience curve due to turnover of personnel.

Group Technology

Group technology is a philosophy based on the principle of grouping similar parts into families, which leads to economies throughout the manufacturing cycle. Similarities can be found between virtually any part attribute; but similarities in part geometry, manufacturing process, and process layout are found frequently in group technology data bases. A group technology data base is equally useful for part design and for process planning, thus making it a natural bridge between the design and manufacturing functions.

Group technology can reduce the amount of time that design engineers spend in designing new parts that are similar to existing parts. The costs of such redundancy is aptly demonstrated by a General Dynamics case in which a virtually identical nut and coupling unit had been designed on five different occasions by five design engineers and then drawn by five draftsmen. These parts were purchased from five suppliers at prices ranging from $.22 to $7.50 each (Hyer and Wemmerlov, 1984).

Group technology can also significantly reduce the number of new parts that need to be designed when a new product is introduced. For example, Xerox typically put 80 percent newly designed components into a new copier model. With use of group technology, only 30 to 40 percent of Xerox's new 9900 copier consisted of new components, which helped cut the design-to-market time in half (Prokesch, 1985).

Group technology can simplify process planning and can provide very useful criteria for facilities layout. For example, similar production processes and production sequences can be a basis for cellular manufacturing. The number of process plans can be reduced also. A consulting firm reported that one of its clients had 477 process plans to make 523 different parts. However, a group technology analysis revealed that 400 of these plans were not needed. Thus, because it took 2 to 3 hours to prepare an average plan, as much as 1200 man-hours were being wasted in their preparation (Brown, 1986).

Computer-Integrated Manufacturing

Each of the preceding technologies has significant impacts on engineering productivity by reducing the amount of time that engineers spend on the tasks that they normally perform. However, computerization without integration still means that the data produced by one function--that is, design--must be downloaded to the data base of another function. Such downloading takes time and increases the chances of transmission error. Also, updating of data bases by batch mode in- creases the chance that one engineer will use data that has not yet been updated by changes made previously by another engineer. As com- puter-based technologies become increasingly integrated, productivity will increase further by reducing the amount of time that engineers spend on sending their work to other engineers and receiving feedback from them.

Ideally, integration means the creation of a common data base from which all design, manufacturing, and business functions can draw. Entries made by any function to the data base would immediately update the data used by the other functions. A number of companies have achieved this level of integration within design, manufacturing, and business functions; but only rarely at present does such integration exist between the functions.

Integration has proceeded slowly thus far because of a lack of common standards for an architecture to link types of computers as well as data bases for graphics and machine communication. A number of national and international initiatives are under way to provide these standard, for example, International Graphics Exchange Standards (IGES) and Manufacturing Automation Protocol (MAP).

COMPLEMENTARY ORGANIZATIONAL CHANGES

Simultaneous Engineering

The process by which most products are manufactured is traditionally developed only after the product has been designed. By that time, the product may have been designed in a manner that severely limits the ability of manufacturing engineers to develop an efficient manufacturing process. Once product designers release a design, they are reluctant to make design changes to accommodate manufacturing engineers. It means tampering with their creation. Also, the engineering design manager may be unwilling to pay for redesign time, and the designers may have been reassigned to work on a different product.

Many American firms have been experimenting with designing the product and manufacturing process simultaneously. This is done by assigning engineers to teams whereby personnel who traditionally have been far "downstream" from product design are able to influence the product design while it is still in a fluid stage. General Motors calls this process "simultaneous engineering" (Vasilash, 1987); IBM calls it "early manufacturing involvement" (Schonberger, 1986). Interaction between design and manufacturing engineers can lead to the design of products that are easier and more efficient to produce. It can also lead to greater productivity among engineers because the design is more likely to be "right the first time," thus reducing the amount of time that engineers spend in creating and responding to engineering change notices.

Effective Utilization of the Engineering Work Force

There is substantial evidence that design engineers are not being used where they can add the greatest value to their companies, mainly in design activities. A study by United Research indicates that American engineers spend 43 percent of their time in design activities (Wolff, 1987). Liker and Hancock (1986) cite a study in which design engineers reported spending only 19 percent of their time on engineering design and the remainder on paperwork and support activities. These design engineers also felt that nearly one-third of these activities could be delegated to secretaries and technicians. These reported percentages do not indicate the amount of time that engineers spend on designing new products versus time spent on engineering changes. The engineers in Liker and Hancock's study reported spending 32 percent of their design time on engineering changes, explaining that they did not have enough time for adequate analysis and test of new designs, and assumed they would be able to "fine-tune" their designs after release.

The solution to the utilization problem is organizational as well as technological. The new technologies discussed above can free design engineers from some activities that they or support personnel currently perform. Some organizational issues concern how the design function is organized. Too much design time is wasted because engineers are taken away from one job and assigned to do another. Schonberger (1986) reports a study indicating that 17 percent of design engineers' time was spent in going back and getting reacquainted with an interrupted job or getting up to speed on a job that was assigned from one engineer to another. A solution to this problem is to permit a design engineer to stay with the same assignment until the design is released to production. Also, any action, such as dual career ladders, that discourages turnover and encourages engineers to remain engineers rather than go into management will help.

Finally, Liker and Hancock also reported in their study that a high percentage of a design engineer's time was spent trying to gather information either from within the design department or across functional boundaries. Only about one-third of the latter attempts to gather information were successful, encouraging the engineers to complete their own assignments at the expense of system integration. Cross-functional teams will reduce some of this wasted information gathering time.

Cross-Functional Relationships

As many of the preceding examples demonstrate, there will be a significant increase in the frequency with which engineers will have to work with engineers from other disciplines. They will need sufficient knowledge of these disciplines as well as experience in working with those who specialize in these disciplines. Exposure to general theory about the materials and methods with which these engineers work will help to facilitate adaptability between disciplines. Some of the most typical cross-discipline interactions will be between electronics, mechanics, and hydraulics. Significant interactions will take place between those who specialize in hardware applications and those who specialize in software.

There also will be a significant increase in the frequency with which engineers will have to work with personnel from other organizational functions (e.g., marketing, accounting, human resources, and strategic planning).

Cross-functional and cross-disciplinary classroom training can provide only part of what is needed for successful projects. However, management must also consciously plan to provide engineers with opportunities to learn on the job through varied cross-disciplinary and cross-functional team experiences early in their careers--for example, by systematic rotation between assignments to assure exposure to varied disciplines and points of view.

Hewlett-Packard Products Division assigns R&D engineers to the mechanical engineering departments and the mechanical engineers to R&D. These assignments may be from 3 months to "permanent." Engineers are rotated in this manner to combat bad coordination. As a result, Hewlett-Packard has reduced the amount of time it takes to get a new product into production from 7 or 8 months to 1 or 3 months (Schonberger, 1986).

CONCLUSIONS

A review of the productivity implications of the preceding technologies indicates that they can produce significant savings. The types of savings reported are (1) the time an engineer takes to perform an assigned task, (2) the time an engineer takes to send or to receive information from another engineer, (3) elimination of duplicated work by access to a common data base, (4) standardization of procedures across departments, and (5) development of a cumulative knowledge base. None of the studies reviewed suggested that firms were translating their productivity gains into use of fewer engineers. There was some indication, however, that these gains were being translated into use of fewer technicians, many of whose tasks were now being performed by the new technologies. If this trend is representative, then management may have to retain engineers more consistently during business downturns because fewer technicians will be available to do engineering work when the demand for engineers tightens. In addition, one hopes that management will use its newly available resources to best competitive advantage. The uses suggested early in this paper will increase the knowledge and skills of a firm's engineering work force.

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PERFORMANCE OF ENGINEERING FACULTY IN THE UNITED STATES

F. Karl Willenbrock
American Society for Engineering Education

OVERVIEW

For the past decade, there has been a shortage of engineering faculty members in the United States. The most recent (1985-86) data from the American Society for Engineering Education (ASEE) indicate from a survey of engineering deans an 8.8 percent vacancy rate of funded faculty positions. This rate has been unchanged for the last several years, and with no indications that it will change in the near future. The current rate of production of U.S. Ph.D.s is inadequate to supply the anticipated loss of engineering faculty members from retirement, death, or other employment.

The schools of engineering have responded to this shortage by hiring foreign-born Ph.D.s at an increasing rate. At present, the appointment of new assistant professors is roughly 50 percent foreign-born and 50 percent U.S.-born. Thus, the engineering schools have systematically exploited the availability of foreign-born graduate students who have completed Ph.D. programs in U.S. engineering schools.

There are a number of negative consequences of the increasingly high percentage of non-U.S. faculty members. Although the foreign-born faculty members are generally well-qualified in their technical specialties, many are not familiar with the U.S. industrial complex, and most are blocked by security regulations from participating in joint programs in many federal laboratories or with defense-related industrial companies. The increasing number of university-industry linkages, a nationally recognized objective that provides mutual benefits to both participants, is not accomplished as readily with foreign-born faculty members.

A number of adjustment alternatives are available to schools of engineering, although none is adequate to compensate for the faculty shortage. One effect of the shortage is to make faculty careers less attractive, and that exacerbates the shortage. One approach is to obtain faculty services from nontraditional sources--for instance, to obtain part-time services from engineers who either are employees of industrial organizations or governmental agencies or are recent retirees. Another alternative is for current faculty to undertake larger teaching loads. Some of these alternatives may result in a dimunition of the quality of the student's educational experience and the research output of the faculty. Another type of adjustment to the shortage is to increase the productivity of current faculty via professional development programs.

Through the use of a variety of contemporary information-handling techniques, it is possible for some educational programs to be delivered to students located in both near and remote locations. A concern with some of these techniques is that they may also decrease the quality of the educational experience of the students.

It should be recognized that there is a wide spectrum of engineering schools in the United States so that generalizations are not valid in many specific cases. High-prestige schools with major externally funded research programs are more able to recruit faculty and, so, are less dependent on foreign-born candidates. However, other schools have essentially no other alternatives available to them. Also, it should be recognized that the hiring of well-qualified candidates is in most cases independent of national origin. However, when a school is able to attract only foreign-born applicants, it is clearly not operating from a position of strength. The overall quality of engineering instruction is liable to be degraded in such circumstances.

Some proposals by which engineering schools might be able to increase their attractiveness to intellectually able U.S. Ph.D. recipients need to be explored. However, in the long term, an inability to supply more high-quality U.S. faculty members in engineering schools will undoubtedly lead to diminished quality in the available educational programs in the United States.

INTRODUCTION

The quality and quantity of the faculties of U.S. schools of engineering are of crucial importance to the nation's future. The nation is dependent on these faculty members to provide the education needed by its technological work force. The capability of that work force in relation to those of our industrial and military competitors will determine whether the United States is economically strong, militarily secure, and able to enjoy a high standard of living. In this paper an assessment of the current status of engineering faculty will be made, trends will be examined, and a current dilemma will be described. The causes of the dilemma will then be identified, and possible remedies will be proposed.

CURRENT STATUS OF ENGINEERING FACULTIES IN U.S. SCHOOLS OF ENGINEERING

Quality

Currently, some 267 schools of engineering in the United States offer accredited programs in engineering and employ more than 26,000 faculty members. Although all of these schools offer programs above the quality floor defined by the Accreditation Board for Engineering and Technology (ABET), the quality of the faculties involved varies widely. They may be roughly separated into two major categories: those that are research-oriented and those that focus on teaching.

In the top research-oriented schools, a significant number of engineering faculty members have attained national and international recognition. More than half of the 574 academic members of the National Academy of Engineering (NAE) are in 10 schools. Of greater importance is that such schools attract the best faculty members and students from the United States and abroad and can compete with top industrial laboratories in recruiting Ph.D. recipients. They also support major externally funded research programs.

In the 32 schools that support externally funded research programs of more than $10 million per year and include three-quarters of all academic NAE members, the quality of the current faculty is strong. They have the ability to recruit both U.S. and foreign-born faculty members of high quality. They usually cannot compete as effectively with top industrial laboratories in the recruitment process, and their dependence on foreign-born faculty members is higher.

There are 87 schools that grant more than 10 Ph.D.s per year. They typically have several departments in which there is a substantial research effort of an above-critical size. Overall, they vary in their ability to attract faculty members of top quality from the United States or abroad. Their dependence on foreign faculty members, particularly from the Asian and Middle East countries, is much stronger.

Of the more teaching-oriented schools, some 78 offer fewer than 10 Ph.D. degrees per year but usually aspire to develop strong research programs. More than 100 schools focus their efforts solely on undergraduate and master's degree programs and do not offer the Ph.D. In such schools there is little ability to attract capable U.S. faculty members in fields in which there is active industrial competition. Thus, their desire to maintain a quality faculty will result in their recruiting primarily foreign-born Ph.D.s from the large number that complete their graduate work in U.S. schools and wish to remain here. The quality of the instructional capability of such faculty members varies, depending on their abilities to understand the U.S. engineering environment and to communicate effectively with U.S. students.

Quantity

Considering now the quantity of engineering faculty in the United States, the ASEE survey for the 1985-86 academic year revealed an 8.8 percent vacancy rate for funded faculty positions. This rate has been stable for a number of years but is lower than the vacancy rate in the late 1970s. While the strongest schools--which pay an academic-year starting salary in the $40,000 range to an assistant professor with a new Ph.D. and can provide start-up research funding of approximately $100,000--do not have serious recruiting problems, most schools are unable to fill their faculty positions with qualified U.S. candidates, particularly in those fields of greatest industrial activity. Their ability to pay attractive salaries and supply new faculty members funds to help initiate their research programs is restricted.

Obsolescence

The up-to-dateness of the current engineering faculty also varies widely. With faculty careers now extending to more than 40 years and with the tremendous changes in technology and engineering practice in the past several decades, the problem of faculty remaining current in their knowledge of the best engineering practice is increasing in severity. While one engineering dean estimated that only 10 percent of his faculty members are not up-to-date on current engineering theory and practice, estimates of 30 to 40 percent would be closer to average. The percentage of faculty members who use computers with facility in both their teaching and their research is usually estimated to be below 50 percent.

Although the sabbatical leave system provides a means for faculty members to update their technological capabilities, it is not available to all faculty and is only partially effective, since the need to cover one-half of the academic year salary requires teaching or research in an area of existing competence. Some new programs related to the professional development of faculty are being initiated in order to provide faculty with systematic ways to keep their technological knowledge base and teaching skills current.

TRENDS IN U.S. ENGINEERING FACULTY

The most notable trend among U.S. engineering faculties is their "foreignization." Although the nationwide average of foreign-born faculty is approximately 20 percent, the increase in the rate of appointment of foreign-born faculty is high, particularly in those technical fields in which there is a strong industrial demand and in those engineering schools that do not have high prestige. This trend in U.S. engineering faculty is not due to a very large increase in foreign graduate students in engineering but, rather, to the inadequate number of U.S. engineering students continuing graduate study to the Ph.D. level and seeking academic careers. Currently, 50 percent of the newly appointed faculty members in engineering are foreign-born.

Another trend among U.S. engineering faculty is that their average age is increasing. The increase in retirement age to 70 years and beyond means that the graying phenomenon is strong among engineering faculty members. While this source of talent can, in some cases, be of great benefit to the schools, it can also result, in some cases, in a prolongation of the teaching of obsolete engineering course material.

A final noteworthy trend in U.S. engineering schools is the increasing gap between the stronger schools and the others. A number of factors have tended to widen the gap. The increasingly close ties between universities and industry have had this effect. The industrial companies that have coupled strongly with universities have been very selective and have usually donated funds and equipment and developed joint research programs primarily with the strongest schools. Also, programs such as the National Science Foundation's Engineering Research Centers and the Department of Defense's University Research Initiatives have been focused on the stronger schools. An overall effect has been that the benefits of close ties to technologically sophisticated companies have been much greater for the stronger schools. The weaker schools have not had the benefits of such ties.

A DILEMMA IN ENGINEERING SCHOOL FACULTIES

A characteristic of the immediate post-World War II era was an upgrading of the intellectual level of engineering education. Major changes occurred in curricula, the GI Bill of Rights helped to produce a large number of highly motivated students, and the new policy of federally funded research in universities developed a more research-oriented faculty member. A large growth occurred in the number of engineering faculty members. The entire engineering education system acted as a funnel to identify the most capable students at the undergraduate level, to encourage them to go to top graduate schools, and to encourage the most able Ph.D. recipients to become faculty members. The system for granting tenure served as a final filter to grant without-limit-of-time appointments to the most able engineering educators. Faculty positions at that time were sufficiently attractive to the most able U.S. engineering students. These faculty candidates, as well as top foreign-born candidates, gave the engineering schools a superb spectrum of choices and led to the outstanding achievements of the engineering schools in the 1950s, 1960s, and early 1970s.

The problem faced by engineering schools today is that this system is no longer operative. Many of the most able U.S. undergraduates accept attractive industrial offers after receiving their baccalaureates. Many of the most able research-oriented Ph.D. recipients find industrial research opportunities more attractive than academic careers. The inability to attract enough top U.S. intellectual talent into faculty positions in U.S. engineering schools is a dilemma that needs to be resolved.

The response of the individual schools to this dilemma has been to hire an increasing number of foreign-born faculty. When there were an adequate number of U.S. Ph.D.s, there was a healthy competition between U.S. and foreign-born candidates, and the practice of hiring the most able candidate added to the intellectual vigor of the faculty. However, the replacement of U.S. candidates by foreign-born candidates has become a means of avoiding coming to grips with the underlying problem of attracting enough U.S. talent of top quality. This problem needs to be faced and solved if U.S. engineering schools are to retain their leading position on a global scale.

CAUSES OF THE INABILITY
TO ATTRACT U.S. FACULTY MEMBERS

The causes of this dilemma have not been systematically analyzed. However, there are a number of plausible explanations. One is that industrial careers in many engineering fields have become much more attractive than academic careers. Companies that invest heavily in research and development (R&D) have built laboratories in attractive locations, provide extensive infrastructure support, and give their most productive researchers many freedoms. The IBM Fellow Program is an example of such freedom in that those selected write their own research agenda. In contrast, federally funded academic research has become increasingly goal-oriented so that academic research is less free and unencumbered than previously. Many engineering students who are not committed to research find that if they wish to climb the industrial company ladder quickly, they should start their careers at the baccalaureate level or pursue additional education in nontechnical fields. In these cases, they are not even exposed to the possibility of an academic career.

Another explanation is that academic careers in research-oriented universities have some characteristics that are not as attractive in the long term as careers in industry. As federal funding of research in universities is increasingly viewed as a purchase of research services and less as an investment in the nation's future, as funding levels needed to support an active laboratory-based faculty member and his or her research group have grown to the order of $250,000 per year, and as complex instrumentation and computer services have become more and more expensive, the research-oriented faculty members operate on a type of treadmill. They must continue to obtain funding at high levels without interruption. Over a 40-year time period, this requirement is a severe one. Areas of technical interest change, the funding levels of federal agencies vary for reasons unrelated to research productivity, and new technologies replace older ones. The financial structure of U.S. universities is such that there are few flywheels. There are very few mechanisms to support senior faculty members who wish to convert from one field of specialization to another. Yet several such conversions are expected over a 40-year career span in engineering.

Another characteristic of current academic careers in U.S. engineering schools is the relatively high teaching loads combined with a dearth of teaching assistants with English-language facility and an ability to relate to U.S. undergraduates. Thus, the time required to do a creditable job of teaching has been increased as undergraduate enrollments have expanded, faculty vacancies have remained unfilled, and a higher percentage of the full-time graduate students are foreign-born.

A final characteristic of academic careers that decreases their attractiveness relates to salary practices. While the strongest schools have raised their starting salary levels to a point where they are competitive with much of the industrial marketplace, the financial resources of most universities are such that there is severe salary compression. The average salaries of senior faculty members can be less than twice the starting salary of assistant professors. While many senior faculty members make major additions to their income through their consulting activities, which are frequently professionally as well as monetarily rewarding, such activities can become essential and not optional in order to maintain a desired standard of living.

POSSIBLE REMEDIES

The thrust of the argument in this paper is that the lack of interest of top-quality U.S. students in pursuing academic careers in engineering has led to an increasing "foreignization" of U.S. engineering faculty. The generally desirable practice of recruiting top-quality faculty on a global basis has become an adjustment mechanism to make up for an inadequate supply of U.S. talent. The possible remedies are both long term and short term in nature. The long-term objective should be to make faculty careers more attractive and more productive. The pool of U.S. talent available for faculty careers needs to be increased.

There are both traditional and nontraditional sources of U.S. talent. The use of industrially or governmentally employed engineers as part-time members of the teaching and research faculty can be expanded. The barriers to such use are, in large part, due to the rigidity of the traditional pattern for appointment to a tenured faculty position. While preserving the prestige and filtering process inherent in the tenure-granting process, it should be possible to define other faculty positions that will both allow and encourage carefully selected engineers whose major employment is not in academe to contribute to the teaching workload. Such positions, although differentiated from the usual professorial status, should not be considered second-class by regular faculty members and, most importantly, by students.

Another large nontraditional talent source resides in women and underrepresented minorities in the U.S. citizenry. While the causes of the underrepresentation in engineering of women and some minorities are complex and extend far beyond the academic community, the academic community cannot afford to be other than proactive in seeking workable remedies. There are successfully regional models, which should be used to confront the specific problems on a nationwide basis.

Of crucial importance in making an academic career attractive is to exploit the positive aspects of a university community. In a well-functioning academic community, there is an intellectual excitement and stimulation, which comes from the interaction of creative people. The routine aspects of academic operations cannot be allowed to mask the satisfactions inherent in the learning and teaching processes. The high goals of contributing to the human knowledge base and of introducing to the young the knowledge gained in the past can create an environment of great appeal to intellectually able individuals.

Turning now to the productivity of faculty members, contemporary communication technology and the innovative use of the present faculty talent can increase productivity. This can be a possible response to the current quantitative shortfall of engineering faculty. There is a need for experimentation in new teaching and learning methods. However, such experimentation is costly in time and may require new instrumentation. Unless external funding becomes available, very little experimentation will be undertaken, and current procedures will continue to be used even though they may be relatively cost-ineffective. Some new programs related to the professional development of faculty are being initiated to provide faculty members with systematic ways to keep their technological knowledge base and teaching skills current.

SUMMARY

The academic marketplace has adjusted to the inadequate supply of U.S. faculty members by a sharp increase in the hiring of foreign-born faculty members. While a balanced hiring of both U.S. and foreign-born faculty has been a highly successful strategy in the past, the present situation in unbalanced. When new faculty hires approach 50 percent foreign-born, U.S. engineering schools face a future that is very different from that of the past. Many will decrease their American characteristics and also weaken their contact with the industrial sector and parts of the U.S. federal funding agencies. Such changes are not healthy. Public policy should be directed to a reversal of these trends.

ASSESSMENT OF HIRING AND PERFORMANCE OF SCIENTISTS AND ENGINEERS ENGAGED IN INDUSTRY R&D ACTIVITIES

Russell G. Meyerand, Jr.
James R. Bogard
Stanley A. Brodtman
United Technologies Corporation

OVERVIEW

A substantially smaller number of young people are expected to enter the work force each year during the 1990s, and there are predictions of many more new jobs being created than can be filled from this reduced labor pool. The people to fill new technology-oriented positions and to replenish vacancies in existing technical areas created by retirements, deaths, and changes in career fields must come from this same labor pool. To compensate for the expected shortfall in the availability of competent technical talent, adjustments may have to be made in the standards used to recruit, retain, and assign technical personnel. Alternatively. other techniques may be used to enlarge the technical talent pool. These alternatives include:

- Cross-training of personnel with degrees in other disciplines;
- Upgrading of technicians to scientific and engineering positions; and
- Utilizing elements of the labor pool in nontraditional ways.

The opinions of experienced managers in two *Fortune* magazine "top 50" companies are used to assess whether employment standards for technical personnel have been lowered during times of tight technical labor markets and to assess the viability of the alternatives for enlarging the pool of technical talent available to satisfy industry needs. Methods of assessing the productivity of technical personnel are discussed.

INTRODUCTION

Fewer young people are expected to enter the work force each year during the 1990s than at present, and many new jobs are predicted to be created over the next 13 years. The result is expected to be a substantial shortfall of qualified people to fill these jobs unless a viable way can be found to use the existing work force more effectively. Secretary of Labor William Brock has said, "We are simply going to run out of people with the skills to hold the jobs that are being created."[23] From this same pool of young people entering the job market each year must come the technically trained people to fill *new* technology-oriented positions and to *replenish* vacancies in existing technical areas created by retirements, deaths, and changes in career fields.

Before attempting to put in place policies to address future problems, it is useful to assess the success of responses to similar circumstances in the past. Therefore, an attempt has been made to assess the quality and performance of scientists and engineers engaged in industrial research and development (R&D) activities, with particular attention focused on the affects of labor surpluses and shortages on the activities of both the company and the employee. This paper will report experiences involved in making adjustments to the availability of qualified engineering and scientific personnel when the companies employed various techniques including cross-training, promotion of technicians to professional status, and recruitment. It will also touch on indicators and methods of measuring the performance of technical personnel.

METHODOLOGY

This paper is based on the opinions of experienced managers in two *Fortune* magazine "top 50" companies. These opinions have been used to reflect on industry practices, in general, and activities of their companies in particular. Each company is recognized as a leader in incorporating "high technology" into its products. Although both have manufacturing facilities and do business internationally, one is approximately twice the size of the other and has its headquarters in the northeastern United States while the other is located further to the west. One serves the military and commercial aerospace markets as well as being a producer of major industrial systems. The other serves the commercial/consumer market. One has grown through a series of major acquisitions and in recent years has been restructuring to focus more on traditional businesses. The other has grown through its evolutionary spinoff philosophy--developing unrelated business in established groups or divisions and, when these businesses have become large enough to be self-supporting, splitting them off from the parent division to create a new division. This latter company has also found it necessary to restructure to some degree in recent years.

Both companies have been faced with the problem of reassignment or reduction of an existing technical work force due to their restructuring activities and have had an opportunity to evaluate the success of some of their technical employment policies. While both are recognized as major R&D-oriented companies, they are different enough that it is felt that they provide a balanced view of some of the important topics to be treated in this paper.

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[23] Anonymous, Work in the future *AARP News Bulletin* 28(7):13, July-August 1987.

MARKET-DRIVEN ADJUSTMENTS

The availability of qualified technical personnel (scientists and engineers) in tight and loose markets may affect the employer's standards for recruiting, retention, and assignments within the organization in both favorable and unfavorable ways. In a period when there is a shortage of engineers graduating from college and available in the experienced technical pool, there is a potential for lowering recruitment standards. The company that has normally recruited from the first and second quartile may be more interested in graduates in lower quartile ranges of the graduating classes--essentially lowering its quality requirements--than if there were a surplus of technical talent and the company could be more selective.

The concern that the limited availability of scientists and engineers will force employers to make compromises in their standards for hiring, promotion, and utilization may have merit. Requirements for scientific and engineering job openings usually spell out specific academic requirements--bachelor's, master's, or Ph.D. degree--and a desired amount of experience in a particular field or specialization. With few applicants and the job waiting to be done, compromises may be considered: a master's instead of a Ph.D., 4 years' experience instead of 7, a mechanical instead of an aeronautical engineer. Another approach to a tight labor market is to offer additional inducements for qualified technical personnel to work for a particular firm. Higher salaries, enhanced titles, increased managerial responsibilities, and higher moving allowances and housing assistance are among the inducements that can be used to attract recent graduates with advanced degrees. These techniques can also be effective when seeking qualified individuals from teaching positions at colleges and universities and from positions at competitor's establishments. The type and level of sophistication of scientific equipment and computers are added inducements, as well as such programs as tuition reimbursement programs, doctoral leaves, and industry-campus exchanges.

Both companies studied believe that they have not changed their standards for new hires during changes in the market supply of scientists and engineers. In general, they have done whatever is necessary to hire the desired technical talent, including the following:

- Paying higher competitive salaries and fringe benefits;
- Recruiting at more colleges;
- Advertising in more cities and in more media and making more recruiting trips to reach a greater number of experienced people; and
- Spending more time looking for the "right" person.

Their experience has shown that each company *can* get the right person by expending sufficient energy and resources and that they are better off to do this than to accept someone who meets lower standards and to whom they may have to accommodate throughout his/her entire career.

It must be recognized that both of these companies are considered premier high-technology employers who can demand and get the qualifications that they seek in their employees. In fact, one of the companies stated that such a large pool of talent always contacts it about potential employment that "it is a relief when the supply of technical talent is tight." This would probably not be the case for industry in general.

ALTERNATIVE ADJUSTMENTS

There are many alternative ways, other than reducing employment standards when faced with a tight labor market, to satisfy a company's need for technical talent. Each has merit in particular circumstances but must be used with caution. These alternatives include:

- Cross-training of personnel with degrees in other disciplines;
- Upgrading of technicians to scientific and engineering positions; and
- Utilizing elements of the labor pool in nontraditional ways.

Cross-Training

Personnel with degrees either in fields other than the desired technical discipline or in nontechnical disciplines can be utilized in scientific and engineering positions. The hiring or transfer of individuals with nonengineering degrees into engineering positions happens on occasion; however, it is less likely to occur in a strict R&D environment--one involving basic and applied research and development--than it is in a more manufacturing-oriented facility, where there is more flexibility in engineering assignments. Personnel with nontechnical degrees generally require more cross-training than do personnel with other technical degrees. Therefore, it is more likely that a person with a different technical specialty will be the candidate for cross-training.

In a strict R&D environment, manufacturing is at a minimum. Consequently, in these organizations, those groups involved with production engineering, process engineering, quality engineering, and service and sales engineering are necessarily small and provide little in the way of a source of non-R&D engineers for R&D training. Conversely, as business falls off and the need for trained engineers slackens, there are few places where they can be "parked" until business picks up again. If they cannot be utilized or retrained through formal in-house training programs or programs set up at local colleges and universities, the possibility of a reduction-in-force must be faced. In such situations the transfer of technical personnel to the more production-oriented units within a company is a logical attempt to retain within the company as many such individuals as possible. If the reduction-in-force is large, those unable to be placed can be offered to other companies to interview them for positions that will keep them within the engineering field. In production-oriented companies, R&D engineers can be moved quite readily to the non-R&D activities, and they will usually perform well after a period of on-the-job training. It is not a two-way street, however, and experience has shown that the non-R&D engineer who has grown up in the non-R&D areas is not a ready source for staffing R&D positions without a fairly extensive retraining program.

It is both humorous and tragic to recall an engineering recruitment trip to a southern city in which all the interviewees had master's degrees in marketing because there were no colleges in the area offering technical programs. That situation has since been remedied. It points out the need for in-house technical training programs and for advanced technical programs and seminars at local colleges and universities, where advanced degrees may be earned, cross-training undertaken, or knowledge kept current. This latter aspect is quite important in our fast-changing technical society, particularly when an individual has been out of school for quite awhile, to assure that he or she keeps up with the state of the art and stays ahead of the competition from more recently graduated peers.

One of the companies included in the survey noted that when it participated in a Battelle Engineering Survey, a review of the material submitted indicated that the vast majority of the company's engineers and scientists were working in their major field and that the number of nondegreed engineers and scientists, and individuals with nonengineering or scientific degrees, was quite small (approximately 4 percent).

Upgrading of Technicians

With low unemployment and declining enrollments, the upgrading of technicians to engineering positions has become a very viable method of meeting technical manpower requirements. The high standards inherent in an exempt engineering or scientific organization must be maintained yet must permit the flexibility to selectively promote outstanding nondegreed individuals who consistently demonstrate, in the performance of their work, the initiative, background, knowledge, and judgment necessary to undertake the full range of technical problems that must be addressed, now and in the future, in any proposed professional assignment.

In the not so very distant past, the transition of technician to engineer in most companies was, at best, only an occasional occurrence. In the current situation, the technician, particularly the senior technician, in the R&D laboratories works hand-in-glove with the professional engineer or scientist in such fast-changing fields as electronics, optics, lasers, opto-electronics, materials and ceramics, and computers. Therefore, when new knowledge is gained by the engineer or scientist, the same knowledge is often gained by the technician(s) working on the project. Consequently, when openings in the lower technical and scientific positions occur, supervisors are prone to push for the promotion of technicians to these positions, arguing that these technicians are familiar with the work and are already trained--something that would have to be done to some extent with a new graduate engineer should they elect to hire one.

In such situations, caution must be exercised when a claim is made that a technician is performing the "same work" as the professional engineer. An assessment of the engineer's assigned responsibilities, either by the engineer himself or by his or her supervisors, must be made to assure that he or she is engaged in professional or exempt-level work and not performing duties that tend to be of a nonexempt or routine and repetitive nature. In many situations where the technician is thought to be working above his or her job classification, in actuality, the engineer or scientist on the project is working below his or her classification.

The technician ranks today do, indeed, provide a potential source for filling entry- and lower-level engineering positions. In today's arena, the old mechanical and electrical technician has almost been forgotten in favor of high-tech specialists in such areas as optics, electronics, electro-optics, and lasers. The 2-year technical trade and community colleges that graduate technicians with Associate in Science of Engineering degrees are growing. However, the graduates are still too few to meet all demands. Many of these graduates continue their studies toward a full bachelor's degree under the aegis of company tuition-reimbursement programs, thus hastening their promotability to the professional ranks. Since most technicians have less than 4 years of undergraduate education, an education-experience equivalency must be determined. The equivalency must equate experience and education to be equal to a bachelor's degree for those technicians who have not expanded their formal education yet possess the knowledge and ability for possible promotion to professional status. In all instances, the promotion of technicians from nonexempt to exempt positions must be done on the assurance that the requirements of federal wage and hours laws will be met--the performance of exempt-level work at least 80 percent of the time, work requiring the consistent exercise of independent judgment and discretion. Within the central research center of one of the companies, marked success has been achieved in the selective promotion of technicians to professional status, particularly in such areas as electromagnetics, electro-optics, and microelectronics. Published papers and patent assignments attest to the competency and performance of these individuals.

It has been of interest to note that the attainment of a 4-year degree in engineering technology normally does not open the door to professional-level assignments, and those graduates frequently continue their education to obtain the traditional bachelor's degree in mechanical or electrical engineering.

The reassignment of the "unschooled" technician who has been promoted to the professional ranks will always present a problem and highlights the need for extreme caution in evaluating both the requirements of the job to be performed and the background of the technician before such promotions are made. Promotions made in the urgency of the moment, to get a job done, may have painful future ramifications in terms of downgrades, layoffs, and employee morale. To relax professional standards so that promotion of a technician to an engineering level would be relatively easy would be a disservice to the technician, to the professional staff, to the company, and to the company's customers.

It might be well at this point to mention the experience of one of the companies surveyed in reassigning promoted technicians. The company had made extensive use of promotion of technicians to exempt status, so much so that in one of their operations those promoted from the ranks of technicians now number 30 to 40 percent of their technical work force. This was done in accordance with their policy of promoting from within and may also have been a way to give recognition to employees in times when rigid controls had been placed on salary increases while the controls on promotions were less restrictive. The high percentage of the work force that had come from the technician ranks created a major problem for the company whenever it became necessary to change the geographic location of a major operation or to reassign people due to changes in the market for their products. Many employees, particularly the senior technician-engineers, did not want to move to new locations or to new functions and, in accordance with its paternalistic nonlayoff policy, the company's attempts to find comparable level jobs for these employees--with their narrow training, in their existing division or at least within the immediate geographic area--proved to be quite a challenge.

Faced with this problem, the company surveyed its peers in the industry and found that these peers, in general, had followed a much more restrictive policy on promotion from the technician ranks and did not have the same problem, at least not to the same degree. The company also found that, in general, when it promoted a technician to an exempt status, he or she was not replaced and that the technician's duties became spread between the newly promoted individual and the graduate engineering personnel working on the project. Presumably, this caused a lowering of the technical content of the work being done by everyone and diminished the productivity of the group as a whole.

Nontraditional Technical Labor Pools

Electronics, optics, lasers, composite materials, telecommunications, and computer advances as well as advanced defense programs have rekindled an interest in science and engineering. However, the high cost of education, the renewed interest in liberal arts (particularly teaching) with its recent higher salaries, and the declining size of the freshman classes (which is spreading fewer students over more fields of interest) are taking their toll on scientific and engineering enrollments.

On the bright side, Stanford University recently noted a significant increase in the enrollment of women in its technical programs. Workshops to inform teachers and counselors about the nature of technical careers in the 1980s and the importance of encouraging women to take mathematics and sciences throughout high school are now being conducted; recently, one was held at Smith College. Many women stop taking these courses in their junior high school years, thereby effectively narrowing their technical career options before they really know what these options are. Women have already entered the medical and legal fields in increasing numbers and with marked success. Because women are a source of technically trained personnel that should be encouraged and developed to meet national scientific and engineering needs, they should be encouraged to enroll in engineering and scientific curricula.

It is an interesting contradiction to note that businesses and industries are still encouraging employees to take early retirement when in their fifties and sixties, even though mandatory retirement has generally been eliminated and the Congress is enticing older workers to work longer. The government is doing this by proposing the accrual of pension benefits for employees over 65; the eventual rise in the age for drawing full Social Security benefits from age 65 to 67; and in the year 2008, the increase from the present 3 percent to 8 percent of normal Social Security benefits in the credit that a worker receives for each year that he or she delays the collection of benefits after reaching normal retirement age. The older employee represents a logical source of highly skilled personnel, and perhaps it is time to modify early retirement policies in light of predicted labor shortages just a few short years away. Perhaps more formalized programs involving shorter work-weeks, flextime, shared assignments, gradual reduction of the number of hours worked during the last few years, and sabbatical leave will be required to retain potential retirees and to woo already retired persons back to industry.

Another element of the work force that can provide a substantial source of technical personnel is noncitizens, who already make up a large portion of the enrollment in technical graduate schools and do very well in these curricula. Many of these individuals elect to remain in the United States after completing their formal education and seek appropriate employment opportunities. The noncitizen can be a good source of technical talent for companies not engaged in defense-oriented activities. However, companies that are engaged in defense-oriented work, for which security clearances are required of their employees, find it very difficult to employ the noncitizen due to the special handling that must be undertaken to assure that they are kept away from the classified areas.

PERFORMANCE ASSESSMENT

Absolute performance of scientific and engineering personnel is very difficult to assess. The number of patents issued, the number of technical papers published, and the number of special technical merit awards received have often been suggested as criteria for judging performance. However, it is recognized that these indices can only be used to get a general feel for performance. If patents and papers do not come from a particular group (such as technicians promoted to technical-exempt status) roughly in proportion to their percentage of the overall technical population in a company, then their productivity may be less than that of other groups. The absolute numbers of these publications, however, are often determined by budgets, nature of the technical work being performed, management emphasis on patenting and publication, and other factors rather than on the productivity of this portion of the technical work force.

One of the subject companies attempted to define the question of productivity indirectly, in a rather interesting and unique manner. The theory that it investigated was that if individuals are being productive in their technical activities, their supervision will recognize this and will promote them through the technical hierarchy. Therefore, a survey was done of the length of time graduate engineers had been in a particular scientific or engineering grade. One analysis undertaken was to determine what percentage of people were more than 10 years in-grade in various grade levels. The "surprise" that came from this study was that in each of the grades surveyed, only 5 percent of those in-grade for more than 10 years were originally employed by the company directly from college (at all degree levels--B.S., M.S., and Ph.D.), while almost 50 percent of those in-grade for more than 10 years were originally employed as experienced scientists or engineers. Various hypotheses were advanced by the company in an attempt to explain this situation, including the following:

- It may be easier to judge the qualifications of those technical people entering the work force directly from college because they are essentially a pool presorted by honor-point ratios, class standing, and extracurricular activities, for instance--criteria that are generally thought to be less meaningful for experienced personnel. Also, the experienced pool may include a high proportion of people whose unsatisfactory work experience elsewhere has caused them to seek new employment.
- It may be easier for a person coming directly from a campus to adapt to the company culture.
- A manager may "care for and nurture" the new graduate more than he or she would an experienced person and, therefore, the new graduate adapts more easily.
- Often, an experienced person is hired to fill a specific short-term need but is then retained after that job is finished and used in a nonoptimum position.

In the R&D environment, investigative tasks are often ill-defined, at best. This, in addition to the particular engineering or scientific discipline and the results desired, will usually determine the educational background--B.S., M.S., or Ph.D.--and experience level required to handle an assignment. A performance evaluation should reflect how well the individual meets the objectives of the job, normally set in conjunction with his or her supervisor, and how well he or she achieves specific job requirements. The performance of the scientist and engineer in an R&D environment was found to be evaluated in the same way in which technical, nontechnical, management, and clerical employees in other environments are evaluated--through defined performance requirements measured against fair and consistent standards. Obtainable objectives must be established and specific tasks or projects clarified against which the employee will be assessed. However, because the R&D tasks are often ill-defined at the beginning of a project, the assessment process must frequently be done on a subjective basis. This is true whether a team effort or an individual effort is involved; and in a highly technical R&D environment, there are many individual contributors to many projects. Assignments require planning, scheduling, analysis, and documentation so that special requirements such as time, resources, and budgeting of costs can be used to determine whether job objectives are met, exceeded, or not met.

The characteristics or traits of a company and of its employees are usually the same and can be determined from its reputation and performance record. A reliable company provides good-quality products and services, meets its schedules, and makes timely deliveries. It is cost-conscious and innovative, employing the latest techniques and equipment and using quality parts and materials. It attracts good employees: they (1) are highly trained and experienced with the ability to apply job knowledge and skill to technical applications; (2) are innovative in their planning, organization, and carrying out of assignments; and (3) are cost-conscious and schedule-conscious and display initiative and teamwork in performing their jobs and in working with others. Furthermore, they possess communication skills. All of these characteristics or traits are criteria that can be measured with varying degrees of objectivity, and performance standards can be developed for them.

SUMMARY

It is clear from most indicators that a shortage of technical, scientific, and engineering personnel looms in the not too distant future. Falling enrollments in the colleges and universities at a time when technological advances seem to be made on a nearly daily basis do not bode well for filling new technical positions, much less maintaining existing positions that become vacant through normal and early retirements, deaths, and career changes. Based on the experience of the two companies surveyed, employers have not extensively compromised their standards for hiring, promotion, and utilization of scientists and engineers, but there is a potential for this to occur in the future.

With the admitted shortfall of technical personnel, attention should be focused on alternative sources for filling future technical job requirements. Such alternatives include the transfer of non-R&D technical personnel to R&D positions, the selection and promotion of highly qualified technicians to exempt technical positions, and the publicizing of options and opportunities in the various technical fields to encourage more people to enter them. Encouraging women and minorities to enroll in technical courses and schools and the development of programs to utilize the technical talents of the retired population (which, if not yet, will soon be the largest age group in the country) are all equally important. The transfer of non-R&D technical personnel to R&D positions is not the most viable solution, for it is costly and time-consuming to retrain and is done at the expense of the non-R&D jobs. Though such activity is a form of cross-training, it might be better to encourage cross-training through tuition reimbursement programs whereby the engineer or scientist pursues formalized training in another technical discipline and both the company and the employee benefit.

The performance of the technical employees of a company reflects directly on the performance of the company. Their performance can be assessed using defined performance requirements measured against fair and consistent standards. In an R&D environment, publishing in technical journals, giving technical presentations, and being issued patents are tangible, though secondary, indicators of performance, technical competence, and a personal desire to participate in and keep up with current technical literature.

PERFORMANCE OF SCIENTISTS AND ENGINEERS IN NON-R&D INDUSTRIES

James F. Lardner
Deere & Company

INTRODUCTION

The purpose of this paper is to examine the use of engineers by industry when they are not assigned to research and development (R&D) tasks, to determine how the quality of the contribution of those engineers is measured, and to assess the interchangeability of those engineers into other engineering assignments as company and national priorities and focus change. I rely on anecdotal evidence and the long-term experience of a number of senior executives who have been involved in the hiring, training, and employment of non-R&D engineers. The sample companies include three major machinery manufacturers, a machine tool manufacturer, two large electronics manufacturers, a major aerospace company, and a large manufacturing and engineering company. All executives interviewed were themselves graduate engineers involved in a variety of corporate responsibilities. All, however, have been and still are responsible for the hiring, assignment, and development of non-R&D engineers.

The investigation covered four principal areas. First was to determine whether these companies, as a corporate practice, hired graduate engineers directly out of college for nontraditional engineering jobs. Second was to determine how the contribution of engineers working in non-R&D assignments was measured. Third was to determine whether those engineers represented a reassignable resource when corporate priorities or focus changed and to what degree. Fourth was to develop a judgmental evaluation regarding the rate at which engineers in non-R&D assignments become technically obsolete when compared to engineers who work in the R&D environments and what could be done to avoid or slow the trend to obsolescence.

RECRUITMENT AND ASSIGNMENT

In spite of the diversity of the principal business of the companies involved in the study, there was a significant commonality in the way that they all recruited and assigned engineers to non-R&D jobs. Though the breadth and nature of the assignments given to engineers in non-R&D jobs varied, there were a number of striking similarities among the companies. Each hired significant numbers of engineers for marketing and manufacturing jobs. Some extended these categories to subdivisions of marketing and manufacturing or product service, parts quality assurance and reliability, personnel, and safety. An important number of engineers was also found to be employed in manufacturing and corporate management. While specific employment figures were available from only two companies, the executives interviewed stated that the split between graduates hired for R&D assignments and graduates hired for non-R&D assignments varied from 60 to 70 percent R&D and 30 to 40 percent non-R&D to the norm of about equal percentages. All executives mentioned post-hire reassignments that do move people from R&D to other kinds of activities within the company as a factor in placing engineers in nonengineering assignments, but none believed that planned reassignment was a significant factor in moving engineers hired for non-R&D assignments into R&D positions later in their careers.

QUALITY OF PERFORMANCE

Several observations were made by the executives interviewed regarding the quality and abilities of current engineering graduates. Nearly all mentioned the importance of computer literacy in engineering today. As a matter of fact, in comments on most older engineers, regardless of assignment, a consistent criticism was their lack of acquisition of computer skills. This now seems to be considered an essential requirement for successful engineering performance in a majority of engineering assignments. However, there was also considerable comment about the lack of appreciation or understanding of manufacturing and manufacturing problems on the part of recent engineering graduates. Comments ranged from "engineers graduating today are not culturally conditioned in school to accept the reality of the manufacturing environment" to "graduates today don't seem to understand that engineering involves teamwork, not just an individual effort uncoordinated with the whole."

Recent Engineering Graduates

All executives in these interviews were emphatic in stating that the principal reason for hiring engineering graduates for non-R&D or nonengineering jobs was that engineering graduates perform better and achieve results sooner because of the scholastic discipline of their engineering training and the subjects that engineers study. One executive—responsible for highly complex, technical, non-R&D activities—said that it was his opinion that the cost and demonstrated results of training people without science or engineering degrees in his business were so unattractive that his company had almost given up trying.

In regard to preparing newly hired engineers for corporate employment, all companies claimed some form of training or indoctrination designed to bridge the gap between the academic environment and the business world. Three executives specifically mentioned programs that they personally had established in the past but which had died out when they left their former jobs because of promotion. In all cases the training programs were described as "hands-on"; they lasted from 18 months to 3 years and featured a variety of planned exposures to various aspects of the company's manufacturing and engineering activities. It was apparent that all programs clearly relied heavily on a mentor system. One of these companies is now engaged in reinstating such a program with the hope of improving the performance of newly hired engineers in a shorter time period.

Career Engineers

Retraining engineers after they have passed through the initial stages of their working careers is recognized as a serious problem and one that none of the executives interviewed felt his company had addressed adequately. The solution to the training challenge is felt to be complex and expensive, but all executives agreed that the solution of this problem is essential to maintaining adequate performance of engineers almost regardless of the nature of their assignments. The problem can be divided into three issues: retraining employees working in engineering assignments; retraining employees working in nonengineering but closely related assignments; and providing specifically focused training related to a defined job or project and directed to a specific, well-defined purpose.

In the matter of measuring the quality of the contribution of engineers in non-R&D assignments, the reaction was uniform in all eight companies. In every case the employee was judged on the basis of the performance required or implied in the job description of his or her current job. In no case was any formal attempt made to rate the employee on the basis of the quality of his or her engineering work as it applied to the job being done. However, it was stated by at least five of the people interviewed that in nearly all cases, job performance was enhanced substantially by the engineering education of the incumbents. In fact, in some cases those interviewed expressed a belief that without engineering training, it would be too difficult and/or too expensive to train people to perform satisfactorily and that, in a practical sense, only an engineering graduate could do the job satisfactorily. In spite of the high regard that all of the executives interviewed had for the performance of engineers in non-R&D jobs, none felt that their performance was adequately recognized and rewarded by their employers, particularly in regard to selection and preparation of those engineers for senior corporate management jobs.

Impact of Engineering Obsolescence

In discussing the problem of engineering obsolescence, the consensus of the executives interviewed was that given the rate of change of the working environment, engineers could only remain current on the basis of their college education for an average of 10 to 12 years without significant retraining. After that period they appear less able than the recent graduates to deal with current engineering problems and technology. At that point, the newer engineering graduates' advantages diminish, and distinctions between shorter and longer service engineers become much less significant. In the case of graduate engineers not working in jobs requiring the daily application of engineering skills and knowledge, the time in which they demonstrate comparative, improved performance compared to that of longer-service engineers was estimated to be 5 to 6 years, or about one-half of the period to technical obsolescence experienced by engineers working within the profession.

Unfortunately, this produces a situation in which engineering graduates are courted and given special training and attention during the indoctrination period; but later, in an environment or company culture that does not require engineers to undergo constant training to remain current, they become less effective and are given increasingly routine assignments. They become less and less effective contributors to the corporate effort and frequently experience a loss of confidence in their abilities, which further reduces their effectiveness. There are some exceptions to this, of course. Engineers who leave the engineering profession for good and embark on careers that can be learned on the job are not affected. Neither are engineers who take advantage of the educational opportunities offered by employers and pursue continuing education on their own. The victims of obsolescence are the engineers who do not. The achievers are not a majority, however. It is estimated by executives interviewed in this survey that no more than 10 to 15 percent of all employed engineers undertake an organized and continuing effort to retrain themselves on their own initiative. The belief of most of those interviewed was that more structured, more obligatory programs are required to avoid premature obsolescence for the majority of engineers employed.

Unfortunately, professional obsolescence affects both the quality and absolute availability of engineers in industry. The older engineer who has fallen behind professionally is relegated to increasingly routine jobs. Such assignments erode the individual's self-image and confidence, which affects how he or she performs and, subsequently, is viewed by superiors. This leads to further reduction in expectations regarding his or her performance and further reduction in the individual's opportunities to contribute to the organization. This situation has been the subject of a number of studies and innumerable warnings and recommendations by leaders of the national engineering community. Most recommendations focus on the need to establish rather elaborate and expensive academically focused programs for the continuing education of engineers working outside the academic environment.

In pursuing the reasons for the perceived obsolescence of older engineers from a performance point of view (which is what interests industry), it was strongly suggested by the comments of the executives interviewed that the problem of engineering obsolescence may be much simpler than has been thought. One executive summed it up this way:

> The real problem is that older engineers don't have an opportunity to learn how to use the new engineering tools that are being used in the universities, and they don't have a

good means to keep up with "current events" of their particular engineering field.

He further stated that the basic laws seldom change; they are, instead, refined. Sometimes new applications or further extension of the laws occur, but these changes do not of themselves make the older engineer obsolete. The lack of awareness of these changes and of the new tools available, seldom the lack of comprehension or basic engineering knowledge, seems to have the most significant impact on professional obsolescence. The inability to manipulate the new tools or "speak the current language" accelerates the erosion of self-confidence because the older engineer no longer compares favorably with more recent graduates. This seems to be a key issue in the evident waste of engineering talent in the United States today.

There is no question that this is, to some degree, an oversimplification of the problem. In terms of the percentage of engineers affected, however, and the principal issues involved in engineering obsolescence, it is probably a very useful and perhaps valuable insight.

Need for Advanced Professional Training

One additional aspect of training, mentioned by at least two of the interviewees, is the matter of advanced degrees. There is a somewhat limited but very real market for master's and Ph.D. degrees in non-R&D jobs. The short supply resulting from the reluctance of engineering students to make the personal and economic sacrifices necessary to attain these degrees, particularly the Ph.D., forces these companies to seek and recruit graduates of foreign universities (as opposed to foreign graduates of U.S. universities). It apparently does not seem practical to hire engineers with baccalaureate or master's degrees to meet this demand. This problem of additional professional education seems to vary almost in inverse proportion to the proximity of the industrial establishment involved to a major engineering research university: the farther away, the greater the problem.

SUMMARY

Somewhere between 30 and 50 percent of the graduate engineers working in the companies examined in this paper work in non-R&D jobs that vary from those involving considerable daily use of engineering knowledge and skills to those requiring almost none, with the majority requiring less rather than more. Nonetheless, the companies have now and have had for a considerable time a policy of hiring newly graduated engineers for these jobs. Only a minority of graduate engineers in nonengineering assignments have gravitated from engineering to nonengineering assignments in the years after hiring, and most of those engineers move to jobs managing engineers rather than out of the engineering orbit.

In regard to the interchangeability (fungibility) of engineers working in non-R&D jobs and their ability to return to R&D engineering assignments when corporate or national needs and priorities change, opinions are uniform. The degree of interchangeability required to use those non-R&D engineers in R&D-type assignments is considerably limited, and the degree of that limitation varies in relation to the time since graduation. Clearly, there are exceptions to this. In cases where the work assignment is R&D except in name and where, for whatever reason, the individual engineer has kept his or her engineering knowledge and skills current, fungibility is higher. These cases seem to be the exception, however, and probably do not account for more than 15 to 20 percent of the non-R&D engineers.

The matter of assessing the quality of the non-R&D engineer as an engineer is also a problem without an easy answer. For most engineers working in non-R&D jobs, particularly those with limited engineering content, the job performance measurement rarely considers the kind or quality of engineering input that contributed to job performance. Instead, the individual is judged on the results achieved in carrying out a particular job assignment. Thus, a sales engineer is judged on successful sales and satisfied customers; the engineer in manufacturing management is judged on department or factory performance; the engineer in a purchasing function is judged on the quality, cost, and reliability of the suppliers whom he or she has selected. It is believed by the executives interviewed that engineering training is a significant factor in being able to do certain jobs well and in being able to do some jobs at all. It seems apparent that a search of performance appraisals of most people with engineering degrees working in other than a day-to-day engineering assignment will contain little or no specific reference to the quality of the engineering that the individual is capable of. In fact, those "nonengineer" engineers are frequently evaluated by nonengineers who have little or no basis for judging engineering quality.

There is no doubt that American industry wastes an important portion of what it has bought and paid for--that is, the engineers on its payroll--by accepting as fact technical obsolescence and by not addressing the problem of continuing education and training. Discussing this problem with interviewees has made it apparent that universities have not made continuing education, of the kind really required by engineers working in industry, easy to come by.

The issue of whether there are or will be enough engineers is difficult to answer under any circumstance, but it becomes impossible until we know for what they will be needed. However, there is a strong circumstantial case that American industry could not function and compete effectively without the large number of graduate engineers who work in non-R&D jobs, so interchangeability may not be as important an issue in the final analysis as some authorities believe. In fact, there is some evidence to suggest that American industry may not use enough graduate engineers in non-R&D jobs to be effective competitors in global markets.

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