Chapter

The Industrial Market for Engineers

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Chapter 4

The Industrial Market for Engineers

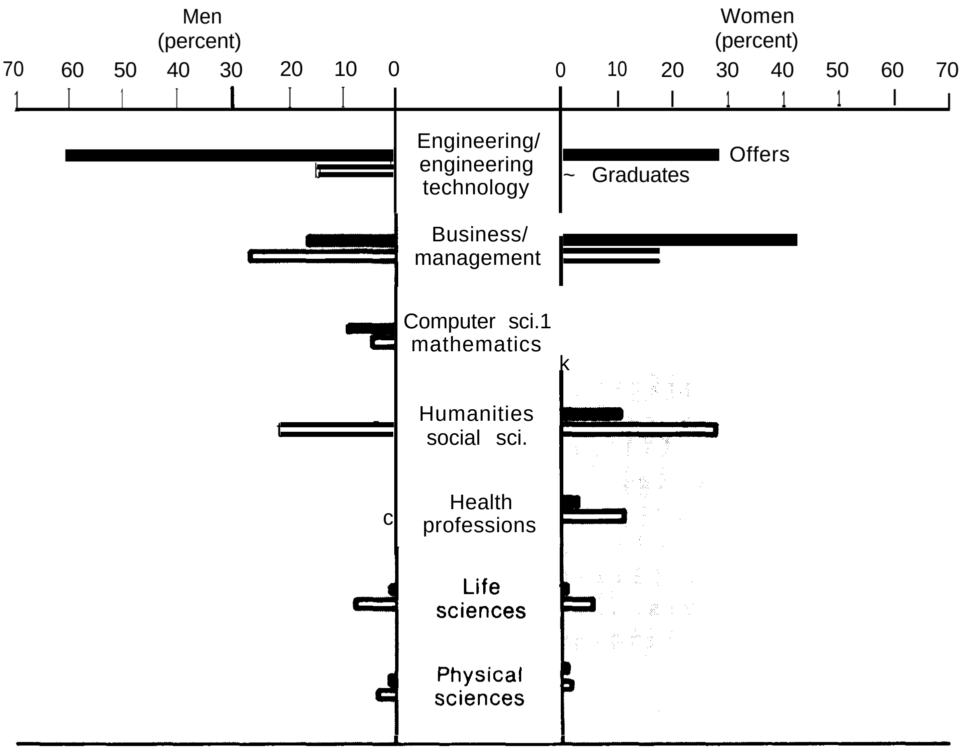
As shown in chapter 2, most science bachelor's degree recipients either go on to graduate school —the Ph.D. being the true entry-level degree for a research career—or obtain employment in a conscience field (see chapter 2, table 2-2). More than three-quarters of all engineering B.S. recipients, by contrast, obtain immediate employment as engineers in industry. In addition, more than 90 percent of all the job offers to all science and engineering bachelor's graduates in 1984 were in engineering, engineering technology, or computer science (see figure -1).[1] Therefore, when considering the utilization of science and engineering bachelor's degree holders, it is appropriate to focus on the industrial market for engineers.

According to the Bureau of Labor Statistics (BLS), the number of employed engineers in the United States doubled between 1960 and 1982, increasing from 800,000 to more than 1,600,000 (see figure 4-2).[2] During that same period, 1960-82, the U.S. gross national product (GNP) increased by 100 percent in constant dollars and the national research and development (R&D) budget grew by 103 percent in constant dollars. Thus, the growth in demand for engineers appears to correlate very well with growth in GNP and growth in total national expenditures for R&D.

[1] *Opportunities in Science and Engineering: A Chartbook Presentation* (Washington, DC: Scientific Manpower Commission, November 1984), p. 32.

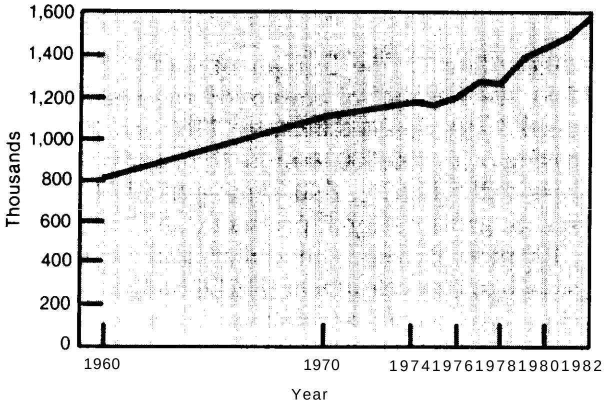
[2] *Engineering Education and Practice in the United States* (Washington, DC: National Research Council, 1985), p. 88. It should be noted that there is a serious discrepancy between BLS and NSF data on employed engineers, the latter showing 1,847,000 engineers employed in 1982, *Science Technology Resources*, NSF 85-305 (Washington, DC: National Science Foundation, January 1985), p. 545.

Figure 4-1.—Percent of All Offers and Percent of All Bachelor's Graduates



SOURCE *Opportunities in Science and Engineering* (Washington DC Scientific Manpower Commission 1984) p 32

Figure 4-2.— Employed Engineering Personnel, 1960-82



SOURCE: *Engineering Education and Practice in the United States* (Washington DC National Research Council, 1985), p 88

The number of first year enrollments in engineering school and the number of engineering bachelor's degree recipients has fluctuated quite widely since World War II, with peaks and troughs apparently produced by transitory political and social events and trends (see figure 4-3).3 However, beneath the fluctuations, there appears to be an overall trend of an increase of slightly less than 3 percent per year in the number of engineering B.S.S awarded each year. The recent surge in engineering B.S. S awarded in 1980 to 1983 appears to be something of an aberration, that could be followed by a decline in the late 1980s, since all previous peaks have been followed by troughs.

The growth in engineering B.S.S has been somewhat uneven across fields, with electrical and mechanical engineers showing the greatest increases over the past decade, as can be seen from figure 4-4,[4] The number of aerospace, chemical, industrial, and mining and petroleum engineering B.S.S have also increased dramatically, more than doubling for each field since 1976. Only civil engineering failed to show a dramatic increase in the 1976-83 period, perhaps because it was the only field not to suffer a decline in the early 1970s.

'*Engineering Education and Practice in the United States*, op. cit., p. 52.

[4]Robert C. Dauffenbach and Jack Fionto, "The Engineering Degree Conferral Process: Analysis Monitoring and Projections, " report for the Engineering Manpower Commission, November 1984, p. 13.

SHORTAGES: PRESENT AND FUTURE

The principal industrial employers of engineers are companies that make transportation equipment (11 percent); communication equipment (6 percent); electronic components (3 percent); and office, computing, and accounting machinery (5 percent). Other major employers include engineering companies (10 percent) and the government (12 percent). Many engineering employers have reported shortages of engineers, especially in the electrical and computer specialties (CS), The National Science Foundation (NSF) annually surveys about 300 major industrial employers of engineers. The table below reports the percentage of surveyed companies reporting a "shortage" of either electrical or computer engineers. [5](NSF defines a shortage as a situation where an employer has "more vacancies than qualified job applicants in a specific field.") Note the dramatic decline in the number of firms reporting shortages between 1981 and 1983.

	Electrical engineers	*Computer engineers*
1981 ......, . .	*57* percent	*51* percent
1982	*31* percent	21 percent
1983	7 percent	6 percent
1984	19 percent	15 percent

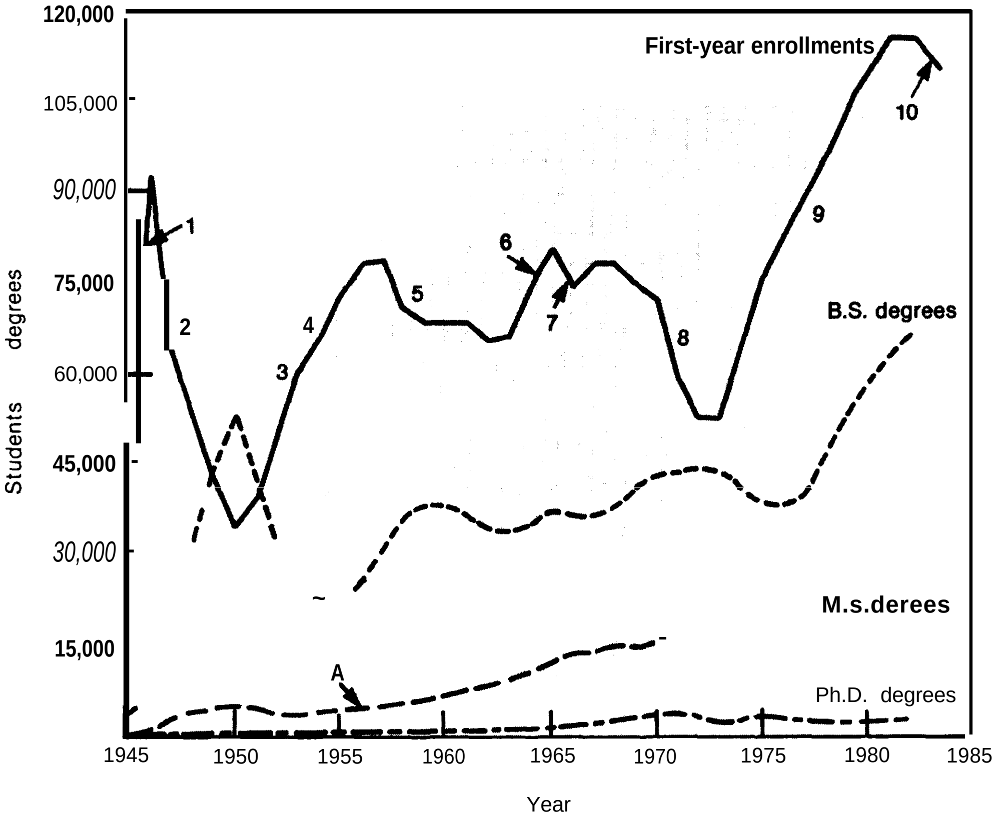
Other surveys report similar results. The 1983 American Electronics Association (AEA) survey of 815 firms employing engineers found that 32 percent reported a shortage of electrical and CS engineers. [6]A similar study conducted among Massachusetts electrical engineer (EE) employers in 1983[7] found 25 percent reporting shortages of "entry-level" electrical engineers, while 65 percent reported shortages of experienced EEs.

"'Shortages Increase for Engineering Personnel in Industry, " *Science Resource Studies Highlight* (Washington, DC: National Science Foundation, Mar. 29, 1985).

'*Technical Employment Projections, 1983-87* (Palo Alto, CA: American Electronics Association, July 1983).

[7]Paul Barrington, et al., "Employment Developments in the Electrical Engineering Labor Market of Massachusetts and the U.S., " Northeastern University, 1983.

Figure 4-3.—Engineering Freshman Enrollments, B. S., M. S., and Ph.D. Degrees

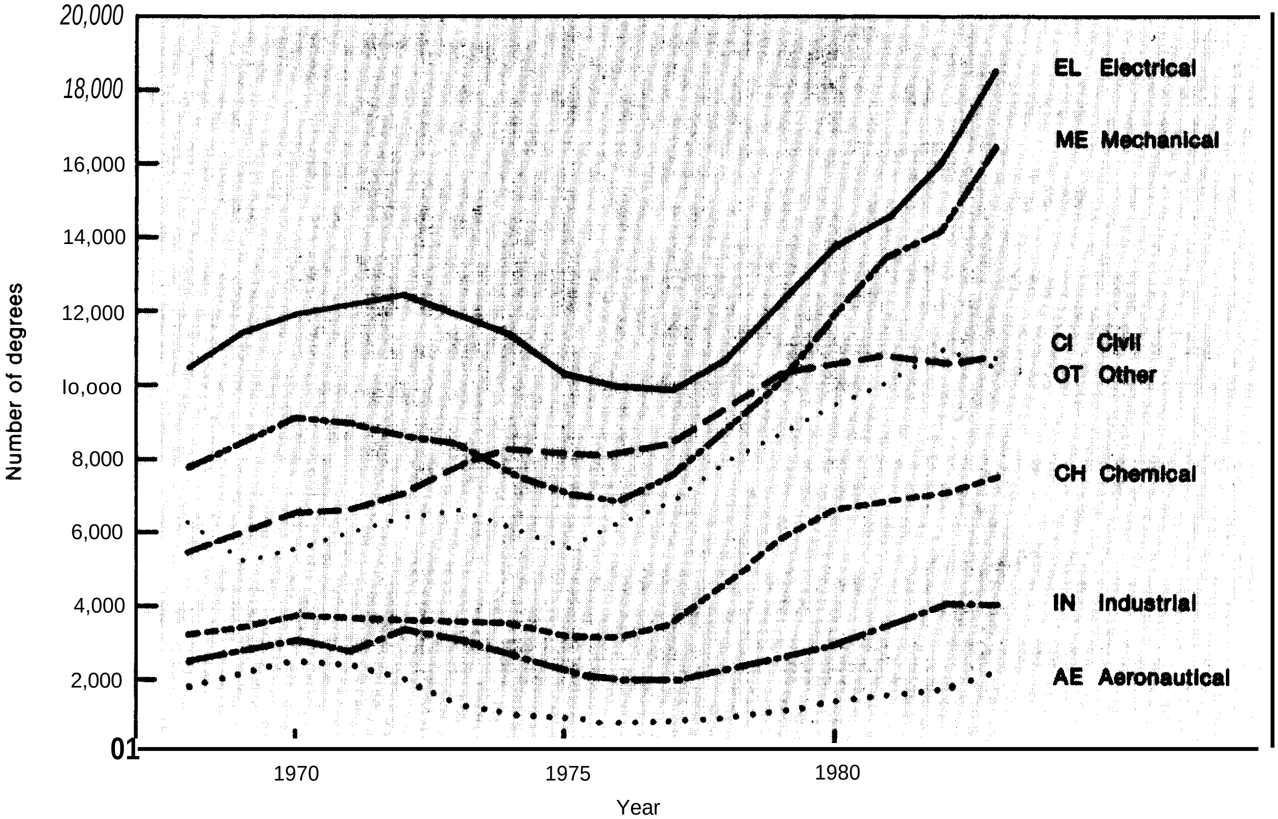


1 Returning World War II veterans
2 Diminishing veteran pool and expected surplus of engineers
3 Korean War and increasing R&D expenditures
4 Returning Korean War veterans
5 Aerospace program cutbacks and economic recession
6 Vietnam War and greater space expenditures
Increased student interest in social-program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

A ASEE Evaluation Report recommends greater stress on math/science and quality graduate education

SOURCE *Engineering Education and Practice In the United States* (Washington DC National Research Council 1985) p 52

Figure 4-.—B.S. Engineering Degrees, 1968-83



SOURCE Robert Dauffenbach and Jack Fronto. 'The Engineering Degree Con ferral Process Analysis, Monitoring and Project ions," report to Engineering Manpower Commission. 1984, p 13

The key question for policy purposes is whether shortages of engineers will be a problem in the future. This question is especially difficult to answer when it is not clear how much of a problem shortages cause at the present time. Shortage reports do not describe the adjustments that employers and potential employees make to shortage situations. Employers have many options available to them, including hiring less qualified personnel and training them; raising wages to bid away engineers from other companies; and rearranging jobs and tasks to better utilize engineering talent. It is clear that such adjustments take place, but there is less clarity about the consequences. Some adjustments may be relatively painless, while others may create as many problems as the original shortages did.

Employees also have options available for dealing with shortage or surplus situations. They can, within limits, move to related and more profitable fields, or seek training in those specialties which are experiencing shortages. The interfield mobility of scientists and engineers, and relative responsiveness of undergraduates to market signals, are two important characteristics of the U.S. scientific and technical work force.

In order to evaluate the possibility and effects of engineer shortages over the rest of the decade, therefore, it is not enough to simply project supply and demand. It is also necessary to understand how employers and employees are likely to adjust to shortage and surplus situations. The principal purpose of this chapter is to lay out a framework for understanding these adjustments, and to summarize the (admittedly skimpy) evidence on their effects.

SUPPLY AND DEMAND PROJECTIONS

Supply and demand projections for engineers are the raw material for evaluating the extent of future engineering "shortages. " In February 1984, the Office of Scientific and Engineering Personnel of the National Research Council (NRC) held a symposium on Labor-Market Conditions *for Engineers: Is There a Shortage?*[8] This symposium brought together the major sources of engineering supply and demand projections: BLS, NSF, and AEA.

All three projections used 1982-83 as their base year. BLS projected engineering jobs through 1995, using a sophisticated variant of the "manpower requirements" approach. First, BLS projected the growth rate of the whole economy and of individual industries. Then it calculated how many engineers would be needed to achieve this growth rate. These calculations were based on historical patterns of engineering employment, plus anticipated changes in these patterns in the future.

NSF used a similar methodology to predict the need for scientific, engineering, and technical personnel over the period 1982-87. Its model, however, gives more attention to specifying the course of defense spending than does BLS.

AEA took a totally different approach. They surveyed their members and asked them to project personnel needs—especially for engineers—through 1987. The individual needs were then totaled. This methodology has been criticized, by W. Lee Hansen and others, as being inherently unreliable. Most employers of engineers do not make firm projections of their manpower requirements beyond the next 18 months, so the responses to the AEA survey for the out-years are largely educated guesses. Moreover, respondents to surveys of this type tend to be overly optimistic about the relative market share their company is likely to achieve, and hence tend to overestimate their personnel requirements.

It must be emphasized that all three organizations were projecting the number of *new* engineering jobs. This is not the same as the *demand* for engineers. Employers not only have to fill new jobs, but they also have to fill vacancies caused by deaths, retirement, movement out of engineering into management or other jobs, or return to school. An accepted rule of thumb is that about 2 percent of the engineering work force will retire or die each year, creating new vacancies. Another 4 percent of engineers will transfer out of engineering into management or some other field. These are not small numbers. **In fact, the replacement demand** in any year is considerably larger than the demand created by new job growth. Thus, the magnitude of any "shortage" depends crucially on how these flows of people are treated.

[8] *Labor Market Conditions for Engineers. Is There a Shortage?* (Washington, DC: National Research Council, 1984).

Under the BLS moderate scenario for economic growth, the number of engineering jobs would increase by 3 percent per year, which is identical to the rate of growth in GNP assumed in the BLS model, and also to the historic rate of growth in the engineering profession. This growth rate translates into 45, OOO new job openings each year. However, an additional 93,5oo engineering jobs will have to be filled each year because of attrition and transfers.

NSF comes up with quite similar projections: an annual growth rate for engineering jobs of 2.6 to 4.5 percent. The low end of the range reflects an assumption of stagnant economic growth (real GNP growth rate of 2 percent) and low defense spending, while the high end reflects strong economic growth (real GNP growth of 4 percent and high defense spending).

AEA projections for demand are much higher: about 50,000 new engineering jobs created each year within the electronics industry alone. According to AEA, the electronics industry employs about one-third of all engineers. Consequently, AEA projections of demand, on an economy-wide basis, are three times higher than BLS and NSF estimates. These high projections clearly result from AEA's use of a questionable methodology.

Supply Projections

There are two major components to supply—new engineering graduates and transfers from other occupations. All three projections agree on the likely supply of entry-level engineers.

BLS and AEA project that the supply of entry-Ievel engineers going into industry will average 63,000 annually, while NSF projects 65,000 to 69,000 annually. (All three projections fall substantially below the number of engineering undergraduate degrees actually awarded in 1983 and 1984 which were 72,471 and 76,931 respectively .9)

The key difference is how these studies handle the transfer component of supply. BLS allows for transfers out of engineering (into other types of jobs or schools) but not transfers into engineering. Thus, BLS makes no attempt to calculate occupational mobility into engineering (though its existence and importance is acknowledged).

The NSF study, by contrast, makes two alternative assumptions about occupational mobility. In the first scenario, occupational mobility into engineering (and each of its subfields) is assumed to be equal to occupational mobility out of engineering. In the second scenario, it is assumed that occupational mobility into engineering takes place at its historic rate, which is just enough to bring supply and demand into balance. The AEA makes no assumption about the magnitude of interfield mobility.

Supply= Demand Gaps

What kinds of gaps between supply and demand for engineers do these projections imply? BLS compares the supply of new graduates to the demand for new jobs, and for replacements due to attrition and transfers and finds that supply only meets 46 percent of the demand for all engineers.

Engineering Education and Practice in the United States, op. cit., p. 57; Scientific Manpower Commission, *Manpower Comments,* January-Februar , 1985, p. 34.

However, BLS is relatively sanguine about the implications of this gap. It points out that in 1980, the latest year with good figures, new entrants also filled less than one-half of total demand. (This was also true over the entire decade of the 1960s, according to OTA calculations.) BLS argues that the remainder came from:

> . . . transfers from other occupations; employed people with previous experience or training in engineering or a related occupation; recent science and math graduates; immigrant engineers; older engineers returning to the profession . . .

BLS concludes that the labor market for engineers in the rest of the decade should be the same as it was in 1980. So, if there were sporadic shortages of EEs in 1980, there should be sporadic shortages in the future.

NSF arrives at roughly the same conclusion, but by a different route. Assuming that occupational mobility into and out of engineering are equal (the first assumption) the NSF study projects a slight excess of demand over supply for electrical engineers in 1987 (2.4 to 7.9 percent vacancies), and a rough balance for the remainder of engineering fields. The second assumption leads, by definition, to a balance of supply and demand. Finally, the shortage predictions of AEA are considerably more severe, due to their use of a questionable methodology.

William Upthegrove presented a commentary at the NRC symposium based on a Business-Higher Education Forum study of *Engineering Manpower and Education*[10] that sheds considerable light on the issue of supply and demand balance. Figure 4-5,[11] taken from Upthegrove's presentation, shows the flow of engineers into and out of the profession. It reveals that when immigrants, bachelors of engineering technology, and B.S. degree holders from related fields such as physics and mathematics are taken into account, only one-third of the growth plus replacement demand must be filled by interfield mobility and upgrading of nonengineers. Upthegrove's flowchart does not take into account the 18,000 new engineering M.S. degree holders who enter the job market each year and are available to contribute to the supply side of the picture. With these included, the supply-demand balance would look even more favorable.

[10] Business-Higher Education Forum, "Engineering Manpower and Education—Foundation for Future Competitiveness, October 1982.
[11] *Labor Market Conditions for Engineers: Is There a Shortage?* op. cit., p. 64.

Defense Needs

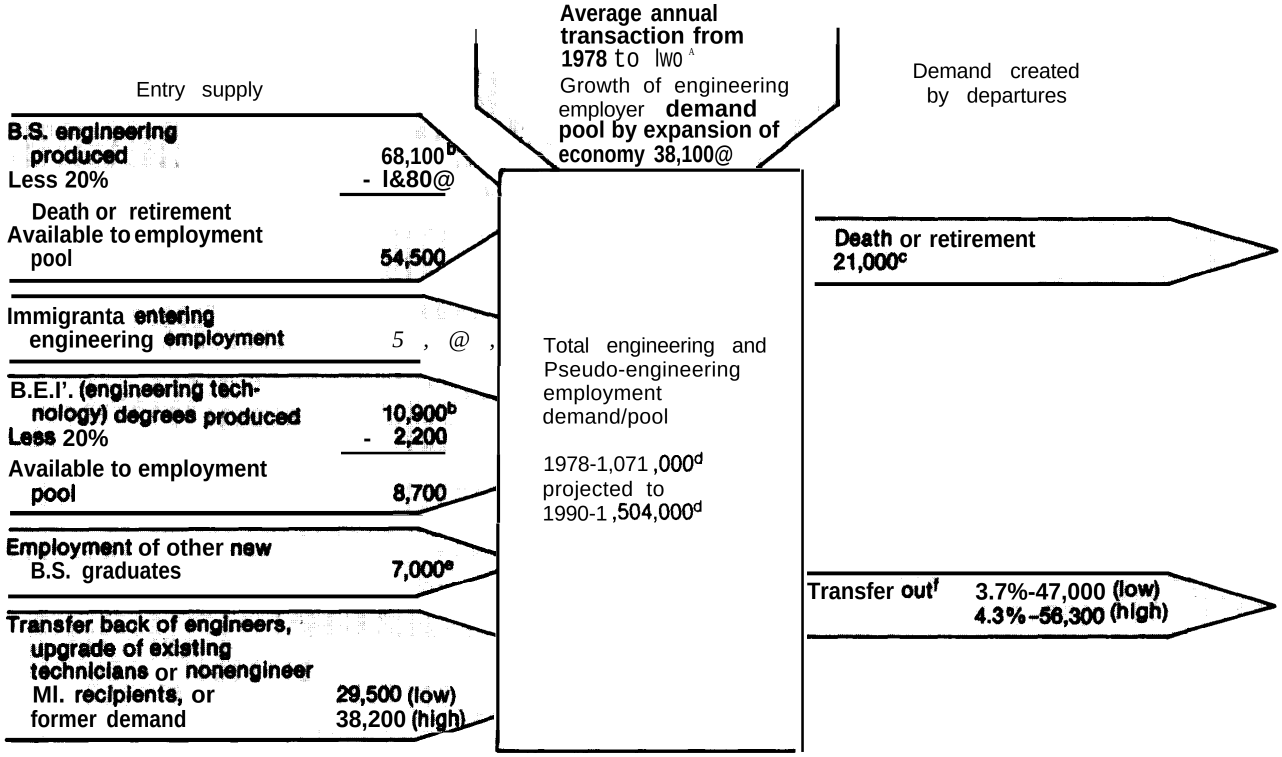
Before proceeding to look at labor market adjustments to shortages, a key question that must be examined is the effect of defense budget increases on the demand for engineers. How sensitive are the projections of engineering demand to changes in defense spending?

AEA asked its respondents to identify the portion of their projected future requirements that were based on the assumption of receipt of defense contracts. The purpose of this question was to avoid the problem of double and triple counting, where several firms project the same hiring requirements based on receipt of the same defense contracts. The response to this question can be used to estimate the effect of increased defense spending. According to the responses, 16 percent of their projected requirements were based on anticipated defense contracts. Hence, even a doubling of defense spending would not have a large effect. This conclusion is buttressed by the results of Barrington, et al. 's survey which reported that "most respondents did not see increasing defense outlays as a key cause of future shortages .'"[12]

[12] Barrington, et al., op. cit

Figure 4-5.—Supply and Demand for Engineers, 1978-90

Total supply = 104,700 to 113,400 per year.
Total demand (growth + death and retirement + transfers out)
= 104,100-113,400 per year.



[a] M L. Carey (Bureau of Labor statistics), "Occupational Employment Growth Through 1990," *Monthly Labor Review*, August 1981. These data from "low" growth Projection.
[b] Averages determined from values of table 18 in National Center for Education Statistics, *Projections of Education Statistics to 1988-89* (Washington, DC: U.S. Government Printing Office, April 1980); and 1990 values from NCES Bulletin 81-406, Feb. 13. 1981.
[c] Occupational Prelections *and Training Data, 1980 Edition*, Bureau of Labor Statistics, U.S. Department of Labor Bulletin 2052, September 1980. The 20°/0 figure is probably conservative in light of the increasing enrollments of nonpermanent foreign nationals in engineering programs.
[d] BLS estimates, This estimate is consistent with w. p, Upthegrove's impression that about one-half of foreign nationals who take B.S. or M.S. degrees in U.S. engineering colleges eventually stay in the United States.
[e] Unpublished data compiled in 1978-79 by Daniel E. Hecker, Bureau of Labor Statistics.
[f] Survey of engineering employment 1974-1976 Suggester an average transfer-out of 3.70/. More recent surveys have indicated an even higher rate (unpublished Bureau of Labor Statistics data from Daniel E. Hecker).

SOURCE *Labor-Market Conditions for Engineers Is There a Shortage* (Washington, DC National Research Council, 1984), p 64

NSF studied the impact of different levels of defense spending in more detail, and came to roughly the same conclusion. It looked at two different levels of defense spending–the "high" projection which assumed a 45-percent increase in real defense spending between 1982 and 1987, and a "low" projection which assumed a real increase of 18 percent over the same period. The NSF study found that shifting from low to high defense spending projections increased the total demand for engineers by 85,000 in 1987. This is an increase of about 6 percent, and has the effect of turning a slight shortage into a slightly larger one.

Thus, increased defense spending can boost engineering demand somewhat, but not enormously. This should not be surprising—only 18 percent of the Nation's engineers are employed in defense-related industries, [13] so an increase of one-fourth to one-third in defense spending (the difference between the high and low scenarios) should generate a 4- to 6-percent overall increase.

There exists a rule of thumb to calculate the effect of defense spending on the demand for engineers. According to Landis, [14] an additional $1 billion (1983$) in military spending will generate a demand for about 1,000 additional engineers if the funds are spent on procurement, and about 4,000 additional engineers if they are spent on R&D. On the average, electrical engineers should make up about one-fourth to one-half the additional demand.

Finally, we note that although defense spending has a relatively small effect on overall levels of engineering demand, it may have a very large effect on specialized subfields. It is impossible, however, to generalize about these localized demand effects. In the next section we will discuss what is known about supply responses to subfield shortages.

[13] *The 1982 Post Censal Survey of Scientists and Engineers,* NSF 84-330 (Washington, DC: National Science Foundation, 1984), p. 60.
[14] Fred Landis, "The Economics of Engineering Manpower," *Engineering Education,* December 1985.

ADJUSTMENTS TO SUPPLY-DEMAND GAPS

The essential nature of a labor market is that it adjusts; supply and demand respond to the surpluses and shortages. A projected gap between supply and demand usually does not indicate an impending shortage; rather, it signals that some sort of adjustment has to take place. Two types of adjustment are possible: The first are adjustments among potential employees, such as an increase in the numbers of entry-level engineers or mobility of experienced workers into shortage occupations. The second are adjustments by employers of engineers who can:

- increase their search and recruiting efforts;
- rearrange jobs to utilize available skills, education, and experience more efficiently;
- make *larger* investments on internal training and retraining of engineers; and
- cut back on production or on R&D.

Under certain restrictive conditions no adjustment is possible. Most projections of shortages assume tacitly that demand and supply are independent, so that there can be no adjustment. This assumption makes sense, however, only under the following very restrictive conditions:

- demand for the final product is relatively unaffected by labor costs;
- supply is not appreciably affected by wage changes; and
- the shortage skills are unique, in that workers possessing them cannot be replaced by workers from other occupations or by new technology,

If *any* of these assumptions are violated, then a projected supply-demand gap will be closed by market adjustment. These assumptions are very restrictive—the latter parts of this section provide evidence to support the prevalence of adjustment.

However, there are two sectors of the engineering labor market in which it makes some sense to assume that supply and demand will not adjust. The first is the defense sector. In defense-related work, the demand for the final product is usually not heavily influenced by the cost (and thus not by the associated labor costs). Moreover, defense-related work may demand very specialized subfields that are in short supply in the short run.

Not surprisingly, the NSF surveys of shortages[15] bear out this observation. About 64 percent of firms with a high proportion of their employment in defense-related work reported shortages, compared to 33 percent overall. Thus, at least in the short run, it makes sense to project supply and demand independently for the defense sector.

[15] "Shortages Increase for Engineering Personnel in Industry," op. cit.

The other sector in which a supply-demand gap actually reflects a shortage are startups. Consider, for example, newly formed companies in the computer industry. Since they are not yet producing a product, they are willing to accept losses in the short run in exchange for the possibility of large returns in the future. Instead of being expected to immediately make a profit, they are competing to get their product to market before their rivals. For firms such as these to cut back on hiring when wages go up would be completely self-defeating, since it would reduce the possibility of achieving profitability at any time in the future. Thus, demand for engineers, in this case, would be independent (within limits) of the wage level. Similarly, if the firm is using cutting-edge technology, the engineers skilled in this technology are likely to be limited in number and not easy to replace.

Supply Adjustments

Outside of the two sectors described above, there are usually adjustments available to narrow potential gaps between supply and demand. The most obvious response to a "shortage," at least in the medium term, is for an increased number of college students to receive training in that field.

Human capital theory predicts that students will, on the average, choose the profession that offers them the highest return on their investment in education.[16] Assuming that educational costs at any college do not vary by major, the choice of major should depend on expected wages and the ease of advancement.

It is not possible to measure ease of advancement, but one can measure wages. Over the past 10 years, the starting wage premium that a newly graduated engineer commands over the average newly graduated professional has fluctuated from a low of 7.5 percent in 1975, to a high of 21.1 percent in 1981.[17] During this period the number of engineering baccalaureates increased from 38,000 to 63,000. Since a large proportion of employers (35 percent in Massachusetts) adjust their wages upward in response to shortages,[18] the recent behavior of engineering undergraduates can be interpreted as a response to a shortage.

Freeman and Hansen[19] have constructed regression equations, based on data from 1949 to 1981, linking enrollments in undergraduate engineering programs to salaries in engineering jobs and in possible alternative occupations. They find that engineering enrollments are very responsive to salary changes: A l-percent increase in real engineering salaries will, by their model, lead to a 2 to 4-percent increase in engineering enrollments.

Despite the responsiveness of college students to market signals, the supply of entry-level engineers can fail to adjust optimally to shortage problems for a number of reasons. First, universities and colleges may not have sufficient resources to meet student demands for a particular curriculum. This could happen because budget constraints or institutional rigidities prevent the university from paying high enough salaries to attract engineering faculty, or from investing in state-of-the-art equipment. Additionally, the university may have difficulty evaluating where a new technology is going and how long the needs for a particular type of training will last. Thus, the university may not want to make an investment in expensive equipment or new personnel in the face of uncertainty over future demand.

Students face much the same problem of having to judge the long-run value of choosing a particular subfield. Even if a new specialty is needed today, students may steer away until it has become better established. Or, conversely, students may react too strongly to current reports of shortages, as that is the only information available. Past student responses to announcements of "shortages" have resulted in surpluses a few years later.

In all of these cases, both educational institutions and students may be acting rationally, given the available information. However, the overall result may not be socially optimal.

[16]Gary Becker, *Human Capital* (New York: National Bureau of Economic Research, 1964).

[17]Douglas Braddock, "The Job Market for Engineers, " *Occupational Outlook Quarterly,* summer 1983.

[18]Harrington, et al., op. cit.

[19]Richard Freeman and John Hansen, "Forecasting the Changing Market for College-Trained Workers, " *Responsiveness of Training Institutions to Changing Labor Market Demands,* Robert E. Taylor, et. al.(eds.) (Columbus, OH: National Center for Research in Vocational Education, Ohio State University Press, 1983).

Occupational Mobility

An increase in the number of engineering B.S.S in response to a wage increase is not a short-term remedy to a supply-demand gap. It takes 4 or more years to train a new engineer in college. In a fast-moving market the needs of employers will have undoubtedly changed by the time entering students graduate. This lag effect is especially powerful for occupations subject to sudden unanticipated surges in demand. The semiconductor boom of the past 10 years, for example, was largely unanticipated. How are jobs in such rapid growth areas filled?

One possibility is that people can move over to these "shortage" jobs from related fields. A large amount of independent evidence exists for such occupational mobility. An NSF study reports that 8 percent of those employed as mathematicians in 1972 had become engineers by 1978.[20] Over the same period, about 5 percent of physical scientists switched into engineering. Overall, approximately one-quarter of all scientists and engineers changed occupations between 1972 and 1978.

Attempts have been made to create occupational mobility models on the level of detail necessary to project supply and demand. Shaw, et al., created a model in which occupational mobility was responsive to wage differences between occupations, as it should be if occupational mobility was to eliminate shortages.[21] Moreover, the magnitude of effects they found were significant relative to the size of current shortages.

The bottom line is that occupational mobility exists, it is responsive to relative demand, and it is important in reducing shortages. It is suggestive that when respondents to the 1983 AEA *survey* were asked how they adjusted to a shortage, almost half reported they would substitute from other special ties.[22]

The major concern about occupational mobility, from the employer's point of view, is that it may lower the quality of engineering work. This was a major theme of the 1984 NRC symposium. We do not have the direct data to evaluate this problem, but we can draw some inferences from the patterns of shortages.

First, as noted above, there have not been many reports of shortages at the entry level in recent years. Thus, any occupational mobility occurring at the entry level —e. g., college graduates who majored in physics but are taking engineering positions—has apparently not been causing serious problems. This can be explained by noting that entry-level personnel—engineers or otherwise—always have to be trained or supervised.

On the other hand, quality does seem to be a problem in hiring experienced engineers. This is reflected both in the complaints of shortages of experienced engineers, and also in the responses to direct surveys. Barrington (1983) asked survey respondents what difficulties they encountered in filling job openings for experienced EE engineers. About one-third cited wage competition as the major problem, but the remaining two-thirds of respondents pointed to "lack of occupation-specific work experience, lack of industry-specific work experience, and inadequate level of training by educational institutions" as contributing to the experienced EE shortage .23

Why should occupational mobility lead to more quality problems on the experienced level than on the entry level? The critical characteristic of an experienced engineer is that he or she be able to work with relatively little supervision on portions of a project. Someone switching occupations, by contrast, will inevitably need additional training and experience. It is impossible to turn a physicist into an engineer with 5 years' experience overnight, although experience in resolving problems and handling responsibilities in one field can be usefuI in another.

The same is true when occupations are defined more narrowly. A major complaint by firms is that there is a shortage of experienced electrical engineers with expertise in particular subfields.

[20] National Science Foundation, "Occupation Mobility of Scientists of Engineers," Special Report 80-317, 1980.

[21] Kathryn O. Shaw, et al., *Interoccupational Mobility of Experienced Scientists and Engineers*, CPA 82-15 (Cambridge, MA: Massachusetts Institute of Technology, Center for Pol icy Alternatives, 1982).

[22] *Technical Employment Projects, 1983-87,* op. cit.

[23] Harrington, et al. , op. cit.

The problem is that experienced electrical engineers specializing in other subfields have not been working fors years on the particular technology required by their new employer. Firms willing to hire experienced EEs without the desired skills, and then retrain them, are probably experiencing some short-term loss in productivity.

Demand Adjustments

Employers of engineers have several available responses to a potential gap between supply and demand. The most straightforward response is to cut back or slow down on research and design work to fit the available labor pool. The shortage disappears because demand for engineers is cut back.

It is hard to know how important this type of adjustment is, but cutbacks are probably the response of last resort. The AEA survey reported that only 4 percent of respondents would consider "cutting back business or reducing projects" in the face of shortages.

In a competitive economy, a firm forced to cut back on projects because of a shortage of engineers could be said to be facing the fact that there are more profitable uses for engineers in other firms. To be more precise, the present value of the expected stream of future profits from hiring this engineer is apparently higher elsewhere.

However, the U.S. economy has large noncompetitive sectors. In particular, both the defense industry and the educational sector do not base their output decisions strictly on profit motives. Moreover, not everyone in the economy shares the same expectations about the long-term usefulness of developing a new technology or product. Therefore, it is difficult to judge whether output foregone by one firm is compensated for by output increased by another firm. If shortages are severe enough, all firms may have to cut back their output .

Increased Search and Recruitment

A more common response to potential shortages is to increase search and recruitment efforts. Search and recruitment options open to employers include increased advertisements, more direct contact with colleges, use of independent recruiters, and attempts to hire experienced engineers away from other firms. The latter response may involve either offering higher wages or benefits.

According to one report, the cost of recruiting a high-tech professional (e.g., an engineer) can be as high as his or her annual salary .24 Thus, the investment of firms in search and recruitment is not insignificant,

Internal Training and Retraining of Engineers

A common response to the tight engineering market is for firms to take on more of the supply burden themselves. In Massachusetts, almost all EE employers offer tuition reimbursement plans, and half of those surveyed had formal in-house training programs for engineers. [zs] According to the AEA survey, approximately 70 percent of respondents, when faced with a shortage, would try to "retrain or upgrade current employ ees. "

Over the last few years several of the maturing computer companies, such as Data General Corp. and Digital Equipment Corp., have adopted more systematic training approaches. Faced with a continuing series of shortages, they have shifted from their traditional "buy" strategy to a "make" strategy for obtaining skilled personnel.[26] This has two major consequences. First, it helps lower the turnover rate, which, in 1979, was 35 percent for the electronics industry compared to 10 percent in basic manufacturing. Equally important, it increases the effective supply of experienced engineers. Since experienced engineers are in shorter supply than entry-level engineers, this may be crucial in alleviating shortages.

Rearrangement of Jobs

The third employer response to shortages is to rearrange jobs and tasks to better utilize the avail-

"Tom Barocci and Paul Cournoyer, "Make or Buy: Computer Professional in a Demand-Driven Environment, " Massachusetts Institute of Technology, Sloan School, October 1982.

[25]Harrington, et a]., op. cit.

[26]Paul Cournoyer, "Mobility of Information Systems Personnel, " Massachusetts Institute of Technology, Ph.D. thesis, 1983; see also Michael Mandel, "Labor Shortages in Rapidly-Growing Industries: The Case of Electrical Engineers, " Harvard University, January 1984.

able skills. It is not clear how prevalent this response is. About 50 percent of AEA respondents would react to a shortage by "increasing productivity of currently employed engineers."

On the other hand, Massachusetts companies did not see this as a possible response to shortages. Barrington reports that "respondents did not see utilization of existing engineering staff as a contributing cause of shortages in the field . . . most firms are unwilling to alter their organizational structures to mitigate shortage problems."[27] These firms may feel that they have already increased productivity as much as they can so that any additional changes would be counterproductive.

Firms sometimes appear to willfully avoid organizational change which would increase profits in the face of shortages. It is important to understand, however, that some institutional rigidities which appear to block the best utilization of engineering talent may in fact be profit-maximizing in the long run. For example, the possibility of promotion into prestigious management jobs may serve as an incentive to get maximum effect out of young engineers. To keep older engineers in engineering jobs could conceivably increase the number of engineers in the short run, but it might have the effect of lowering the total amount of employee effort. Consequently, the refusal of many firms to rearrange their job structures in response to shortages is not surprising.

[27]Barrington, et al., op. cit.

THE CONSEQUENCES OF ADJUSTMENT

To see how well these adjustments to supply-demand gaps are working in the business world, OTA commissioned an in-depth interview study of the market for EEs in the Boston area. Electrical and electronic engineers were chosen because there have been repeated reports of shortages in those fields, because EEs serve both the defense and the civilian sectors, and because employers of these engineers are often producers of new high-technology growth products such as computers and electronic equipment. Interviews were conducted in the Boston area by OTA contractor Dr. W. Curtiss Priest of Massachusetts Institute of Technology (MIT).

The interviews covered 5 categories: large firms (5), small firms (4), engineering school deans and chairmen (4), university placement and employment agencies (4), the Massachusetts High Technology Council Director, and "headhunters" (2). The interviews focused on the availability of the electrical engineer in the Boston-Route 128 region.

In selecting firms, a variety of firms were chosen, reflecting the type of market (defense and civilian) and products. Also, various firms have different reputations for hiring requirements and corporate climates. The typical contact at each firm was the vice president of engineering. The firms contacted were: Raytheon Corp., AVCO Corp., Wang Laboratories, General Electric (GE), Polaroid Corp., Pacer Systems, Inc., Baird Corp., Technical Alternatives, Inc., and Apollo Computer Corp.

Engineering school deans and chairmen were contacted at MIT, Northeastern University, Tufts University, and the Franklin Institute. University placement contacts were at MIT and Northeastern. Employment agencies contacted included Computer Placement Unlimited, Inc., High Technology Placement of Winter, Wyman & Co., Fortune Personnel, and McKiernan Associates.

Nearly all of the interviews were made in person and lasted from 1 to 2 hours in length. An open-ended discussion was conducted with each contact using seven categories of questions. These questions investigated how shortages of engineers vary over the short and long term, the availability of particularly needed skills, and the ability of engineers to grow into job requirements. Additionally, the discussion covered the impact of military procurements, the benefits and environments required to attract engineers, and the sensitivity of universities to market demands. Finally, interviewees were asked to compose a "wish list" in order to identify major concerns about the availability of engineers. To explore the hiring requirements in detail, the respondent was asked to describe a job description and how closely a hire would have to match the description.

Variability in Shortages of Engineers

Each firm had a uniquely different set of experiences regarding shortages of engineers. These experiences depended on the character of the firm, its location, and its reputation. In general, industry responded that there were certainly shortages of some types of engineers at particular times but some firms reported no shortages because of their particular position in the market.

Shortages of engineers vary by *geographic location*. While the focus of the study was on the Boston-128 region, a number of firms had multiple locations across the country. Raytheon Corp. has experienced some shortages in the Boston region but extreme shortages in the Santa Barbara area. Likewise, Pacer Systems has experienced some shortages in the Boston area but more shortages at their Pennsylvania location where there is a higher demand for engineers with substantial military service experience. A number of placement respondents commented on the existence of shortages in the Silicon Valley area because of the very high costs of living.

Shortages vary by the firm's *reputation and Culture*. Apollo Computer and Wang Laboratories stated that they do not suffer from any shortages of engineers. Both firms are successful computer applications firms with distinctive corporate climates and reputations. Apollo Computer has a unique reputation for fast growth and the "Apollo culture." This places the firm in an "unreal, dreamworld existence" in which they can be extremely selective about applicants. In contrast, a company like Baird, an instrumentation firm, often finds it difficult to hire engineers within salary ranges they can afford. They prefer to hire fresh graduates to help keep down salary costs.

Shortages vary *across general areas* related to electrical engineering. Electrical power generation and distribution is an area that depends on the construction market and the demand for electricity. The demand for electrical engineers in this area is fairly steady and the supply appears adequate. The electronics industry, in contrast, has had substantial periods of growth, creating a high demand for the electronics-oriented electrical engineer. There have often been periods of shortages for particular skill requirements in the electronics field. Computer programmers in electrical engineering applications areas have also been in heavy demand. However, there is some indication that 2-year educational programs are successful in meeting the demand for many of these requirements.

Shortages also vary considerably by *special skill needs*. There are certain positions that require both excellent electronics hardware skills *and* strong computer programming skills, such as in the design of the next generation of computers. Qualified people are very scarce. Another current area of shortage is in the use of automatic test equipment (ATE). Knowledge of ATE has become quite specialized to certain machines and software packages. It is difficult to locate people with the required background. Another scarce skill area involves engineers with both analog and digital hardware experience. Many older engineers skilled in analog hardware find it difficult to make the transition to digital hardware. Younger engineers, more skilled in digital work, find analog hardware difficult and foreign.

Changes in markets and opportunities are constantly producing specific skill shortages. The recent emphasis on "automatics" such as robotics and other industrial control machinery has created a heavy demand for industrial electrical engineers. Until a few years ago, industrial engineers were in low status positions and many universities, such as MIT, did not train industrial engineers. Another recent growth area, "very large-scale integrated circuits," has created shortages of engineers both in industry and universities.

Shortages vary *over time* as economic conditions and growth opportunities change. Respondents with 20 to 30 years of experience recall the ebb and flow of hiring over a number of cycles of high and low demand periods. Memories were recalled of how in the late 1960s, half of the employment agencies went out of business, and stories were circulating of engineers driving taxis. More recently, shortages in 1979 and 1980 were remembered in terms of prolonged searches and less than optimal hires. In prior decades, military employment was viewed as unstable and companies such as Polaroid were considered stable and secure. In the current decade, military employment is seen as a refuge and the frequent cycles of civilian layoffs are viewed with greater anxiety. The current softening of the market is viewed by many as a temporary adjustment period.

Shortages are not perceived to vary much by the level of *military procurements.* Many respondents emphasized that the two climates of military and civilian work are so different that there is low mobility between the two "sectors. " The military engineer is viewed as more risk averse, less creative, and less likely to be interested in advancement. In contrast, the civilian engineer is viewed as more people oriented, more talented, better able to bring out products, and more selective. It is more likely that engineers will move into the military sector when civilian hiring is down than will military engineers move into the civilian sector when hiring in the military sector is down. Thus, when military procurements are rapidly increasing, those hiring in the civilian sector sense less competition in hiring the same people than they might if the mobility were higher.

Raytheon, a company with about 75 percent of its engineers conducting military work, indicated that they keep salaries at about the same level for both civilian and military positions regardless of changes in demand for military work. Pacer Systems indicated that tight government auditing practices kept them from bidding up salaries for military engineers. While some of these statements appear to defy the economic laws of supply and demand, they were prevalent enough to warrant further investigation.

Impact of Shortages

In general, shortages tend to lengthen search times and may relax, somewhat, the requirements required for a position. Many respondents stated that, for the most part, the supply of engineers had improved over the last 5 to 8 years. Even during high demand periods, the impact of shortages has not been dramatic.

Changes in the level of shortages of electrical engineers substantially affects the *search time* for a new hire. Responses about variability in search time were fairly consistent. During periods of reasonable availability the search period takes 1 to 11/z months. During periods of greater Shortage, this time can easily double and a search period of 4 to 5 months would not be unusual. In these periods, lesser known firms must be prepared to settle for less desired choices in candidates. Special needs require more search time; the process of hiring the right chief engineer when the requirements are fairly unique can take more than a year.

Shortages have an impact on the quality *of engineers and productivity.* For example, during the recent 1979-80 shortage, a number of respondents said that significant compromises were made in hiring. The level of experience criterion was met less often. Also, firms used to hiring from "first rate" schools might find it necessary to relax their requirements to include other schooIs during high shortages. Nonetheless, there was a sense that no large departures from expectations were ever made. The compromises were significant but not highly burdensome.

Shortages also have an impact on *deferred opportunities.* For example, new hires in specific areas may add to the future research capabilities of a firm, but a shortage in that area presents an "opportunity cost" to the company's R&D effort, Polaroid encountered shortages of Ph.D. opticaI engineers and AVCO described shortages of "hard science" based engineers that impeded expansion of their research capabilities.

A major impact of shortages may be job-*switching and high expectations* of engineers. A "star" engineer (heavily sought after for his or her high abilities and relevant skill area) will often switch jobs every year or two. The change is typically made to receive more responsibilities, work on more challenging problems, and for the corresponding salary increase.

The electrical engineer has fairly high expectations about the job in terms of challenge, good relationships with the supervisor, promise of K&D work, freedom and independence, cutting edge projects, being entrepreneurial in design, and high salary. With a very high degree of consistency, respondents described these expectations and the importance of meeting them to hire and retain the engineer. It was also emphasized that a good salary went along with the other expectations and was not typically sought after as the primary goal.

Mobility and Flexibility of Engineers and Related Professionals

In general, it is difficult for an engineer to take a job requiring work much different than his or her previous experience. There are certain "feeder" fields like math and physics but it is nearly impossible for, say, a chemical engineer to take a position as an electrical engineer, or even for an electrical engineer experienced in radio-frequency design to take a job in computer design. Professionals in *math and physics* are often hired for "systems" work because their general training is useful in general problem-solving and design. They are more likely to be hired by firms engaged in basic research, such as Polaroid and AVCO. They are less likely to be hired by a firm like Apollo Computer. Thus, when the demand is higher for engineers than scientists, as has been the case over the last 10 years, mathematicians and physicists can shift to fill some of the demand. To illustrate the magnitude of this shift, from 1973 to 1983 the number of undergraduates in engineering at MIT (primarily electrical engineers) has gone from 1,257 to 2,405. Over the same time period, the number of undergraduates in the school of science has declined from 1,162 to 725.

Not all engineers are equally "flexible" or "mobile." The engineer in the top *quartile* of his profession is considered much more mobile and flexible than the other 75 percent in the profession. Engineers that have reached positions of management or high rank typically have greater flexibility and mobility than more junior engineers. Three factors seem to play a part in restricting the flexibility and mobility of engineers—market limitations, management restrictions, and know-how limitations. These factors are not independent, but work together to reduce mobility and, at the extreme, to render obsolescent many engineers.

In terms of *market limitations,* firms often change while in a period of crisis. They require particular engineering skills immediately and obtain these skills from the outside market because it is not practical to retrain in-house engineers in the time available. In terms of *management restrictions,* engineers become identified by management as having certain abilities and know-how; it is difficult for management to take the risks associated with allowing an engineer to make a transition to a new skill area.

In terms of *know-how,* engineering is a highly "know-how" intensive profession. It takes considerable training and practice to be proficient in a particular area of electrical engineering and while some of these skills are transferable, many are not. For example, analog circuitry know-how is not highly transferable to digital circuitry. Thus, over the last 20 years when the field was moving from analog to digital, many engineers became increasingly outmoded.

The interviews constantly reinforced this dynamic picture of the way many engineers become unable to face periods of transition. Many respondents spoke of the need for more engineers to "keep up." There were stories about the key engineer who did keep up and how he or she played a significant role in the newer areas, in contrast to those who did not. The placement officer at Northeastern referred to those engineers who worked in the same area for 10 to 15 years and then had to return to drafting or some other occupation requiring less skills when the area dried up. While many professional fields are faced with technological change, the engineering profession is probably more vulnerable than most.

For the more mobile and flexible engineers, the *headhunter* plays a critical and dynamic role. The employment headhunter is a placement person who actively seeks out individuals to meet a client's employment needs. Many employment agencies receive applications from engineers and match these with employment opportunities they have identified in industry. The headhunter goes one step further and attempts to lure a "star" engineer out of one company to another. As disruptive as this first appears, the headhunter plays an important role from the standpoint of economic efficiency. He or she is helping to allocate a scarce resource to a more optimal allocation. The headhunter establishes a network of contacts both within organizations looking for talent and within organizations where the talent *is* "misapplied" *or* "underutilized. "

In matching individuals, the headhunter is sensitive to the flexibility of the employer in terms of the technical capabilities of the individual and the personal match. Often it was said that employers hire "people they like. " Thus engineers from certain styles and cultures of firms are much more likely to fit a particular position than others. But other placement professionals warned against overemphasizing the cultural variable. The bottom line is how well the person can do the job and as monolithic as many firms appear, there are many subcultures within any given organization.

In summary, many factors play a role in restricting mobility and flexibility. These relate to both technical variables and cultural variables. For small incremental shifts in the work force, these factors will not be highly significant. For major occurrences of technological change and large changes in the economy, however, these factors will be quite important.

Desirable Changes

In concluding each interview, participants were asked to identify the most desirable changes relating to the availability of engineers. The responses addressed various availability, quality, and professional issues.

In terms of shortages, people in employment agencies all wished they could have a larger, more capable pool of engineers to draw from. Since they are personally responsible for how well they meet their clients' expectations, this is a significant statement about the shortage of engineers. Within industry, if a firm required a particular specialty which was in short supply, the response was to have more engineers trained in that specialty. For example, the GE generators section wished more schools provided "power systems engineers. " Raytheon, involved in more radio work, wished schools trained more radio-frequency engineers. In many cases, the undersupply was in a low glamour area. Power systems engineers, industrial engineers, etc., are lower status areas and many students prefer the high tech, high glamour areas. Whether "glamour" is a "correct" economic market signal for whether students should pursue a particular area of electrical engineering is an interesting question.

This leads to a very serious issue of the status of engineers in general. Respondents from universities unanimously indicated that they were upset about the "second class" treatment of engineers. One respondent described industry as treating engineers as a commodity while another indicated that engineers are often used for "subprofessional tasks. " The dean of one engineering school suggested that the supply of engineers should be limited, as the medical profession has done with doctors, so that the standards of professional excellence and stature could be raised. The German model was considered a success in maintaining engineering professional standards. There may be a linkage between the status issue and the factors that lead to immobility and inflexibility discussed above. How can an engineer be a professional if so much of his or her know-how can be be made obsolete by the advancement of technology? One response to this dilemma has been to institute "lifelong Iearning. "

Lifelong learning was emphasized by both respondents in industry and in the universities. A recent conference on "Keeping Pace With Change: The Challenge for Engineers" was sponsored by the Massachusetts High Technology Council and held at Northeastern University. In a study sponsored by the High Tech Council, the "half-life" of the engineering degree (length of time half of the knowledge acquired by graduation remains relevant to work tasks) was estimated to be between 3 and 5 years for the Bachelor of Science in Electrical Engineering. The peak age for the performance of engineers, in terms of age, was found to be the late twenties and early thirties. According to this study, productivity typically declines from age 30 until retirement.

To counteract this process, lifelong learning programs have been established within industries and through universities. It was noted that the engineer over age 35 cannot be expected to return to the classroom but needs different educational resources to keep up. The older engineer needs support groups in the company of his peers. One program is provided by Northeastern University where live graduate courses are provided using video to locations along Route 128 in Boston. The system has two-way voice for communication and courier service for homework.

Perhaps, too, with newer information technologies, the engineer can keep pace by greater use of information databases where the knowledge is keyed by function and application. While general citation databases exist such as COMPENDEX on Dialog Information Services, these only provide bibliographic citations to the engineering literature—a literature which is itself surprisingly low on useful material. If the private market cannot respond in providing these information services, it may be a role of government to help meet this need.

Respondents also expressed the wish for engineers to have additional skills beyond basic engineering capabilities. A few respondents emphasized the need for engineers to be better able to communicate and write. A few indicated the need for engineers to be better able to use computer simulation to test a prototype design in place of building the prototype because of the high costs involved in making custom integrated circuits. Two respondents emphasized the need for engineers to have stronger skills in scheduling and planning, and a better sense of management's objectives.

Finally, Polaroid, AVCO, and Raytheon indicated the need for government and industry to provide greater support of hard science and applied research. A vice president at AVCO was highly concerned about the loss of hard science Ph.D.s since the Vietnam War who could not only contribute to military strength but to basic research vital to civilian industrial strength. From the university side, Tufts noted that the current NSF emphasis on large research programs has greatly reduced opportunities to support research at Tufts. The Commonwealth of Massachusetts' program to provide research facilities in microelectronics available to universities and industry was lauded as a way of providing facilities that Tufts could use to educate their engineering students.

CONCLUSION

Shortages exist for engineers, especially for those in a few high demand fields. in the last 5 to 8 years, however, shortages have been troublesome but not a large burden. Some firms have never perceived shortages while others find the supply of engineers much too small. The flexibility and mobility of some engineers is high but for most engineers it is low. The engineering market performs reasonably well for gradual transitions but does not perform well during periods of major technological change or dramatic changes in market and/or economic conditions.

In general, there does not appear to be a need for a direct government role in alleviating potential shortages of engineers. The market for entry-level engineers seems to be functioning well enough now to eliminate shortages. At the bachelor's level, some educational institutions report that they do not have enough resources to train all the engineers that are interested, due to shortages of faculty and equipment.

Although there have been, and will continue to be, spot shortages of experienced engineers, they are not of a type amenable to direct government intervention. When a new technology is developed, it simply takes time before there is a pool of engineers who are experienced with the new techniques. There may be a role for the government in helping to promote the retraining of experienced engineers into startup fields. Mission-agency sponsored R&D programs could conceivably serve that retraining function. The Federal energy and environment programs of the 1970s, for example, helped retrain significant numbers of scientists and engineers to become specialists in those two fields. Many of these people are currently employed in their new capacity by industry.

A fundamental problem is the obsolescence of know-how and the corresponding obsolescence of engineers. In response, many institutions and firms are encouraging lifelong learning. Since government has traditionally played an important role in education, there are some policy options which may help. One important role is to provide basic facilities for education such as the microelectronic center that Tufts and other universities find important in helping train engineers. Another role is to identify economic disincentives to lifelong learning and provide either educational support or tax relief to enable more engineers to keep up their know-how.

In the area of information policy, there is the question of how new information technology can assist in providing ongoing know-how support and lifelong learning to engineers. Does the structure of the market of engineers and their employers encourage the private sector development of such information support systems, or are there public sector reasons for government support? A number of market failure reasons can exist for the lack of the development of such support systems. To the extent that firms do not fully bear the costs of the obsolete engineer, firms will underinvest in further training, etc. Also, information has transferability problems—it is often difficult for the supplier to exact the full value of the information because it is difficult to keep the information from being passed along (with no further revenue to its producer) .[28]

28 For a comprehensive discussion of these and other reasons see W. Curtiss Priest, "The Character of Information, " contractor paper for U.S. Congress, Office of Technology Assessment, Project on Intellectual Property, Feb. 10, 1985.