Chapter 4

Human Resources

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Manufacturing, like the rest of the economy, depends on the competence and ingenuity of workers, from the shopfloor to the executive suite. Sophisticated technology demands able people. Just as powerful machines can enhance the productive abilities of people, it takes well-trained people to get the best out of the machines.

The need for highly qualified people is not confined to an elite; the most productive technologies are those that exploit the talents of skilled people at all levels. This has been a cherished principle of American development, manifested in many ways. One is the commitment of the United States to universal education, probably the most important investment a nation makes in its people. During most of the 19th and 20th centuries, the United States enrolled a larger percentage of its population in school than did European countries.[1] Even now, although there are many serious problems with educational quality, American enrollment in primary and secondary education is among the highest in the world, and in postsecondary education the United States ranks much higher than any other nation. Fifty-seven percent of the relevant age group was enrolled in postsecondary education in the United States in 1987, compared to a weighted average of 38 percent in all other industrial market economies and lower averages for developing and less developed nations.[2] Nathan Rosenberg, describing the factors that led to the rapid rate of technological innovation in 19th-century America, writes,

> Not only did American society devote a large proportion of its resources to inventive activities; it is also apparent that the human resources of the country were well-equipped through formal education with the skills which might raise their productivity both as inventors and as successful borrowers and modifiers of technologies developed elsewhere.[3]

Kazuo Koike, writing about contemporary Japanese manufacturing and skills, puts it this way:

> The essence of the contribution of high morale is . . . in devising better work methods and production, which in turn demand technological knowledge by workers for maintenance . . . This kind of wide-ranging skill contains such knowledge and promotes the ability of workers to determine the causes of problems on the shopfloor and thus to contribute to productivity.[4]

Rosenberg and Koike both stress technological knowledge, and that is no accident. All fast developing and developed nations put heavy emphasis on education-both on high-quality education and on broad participation by all ranks of citizens. Among the developed countries, those best known for their heavy investments in education are either the richest (West Germany, Sweden) or the fastest growing (Japan).

Many leading-edge companies that have been most successful in applying advanced automation in manufacturing put a particularly high premium on the cognitive skills of workers. By replacing human labor in the more routine tasks, they create a greater concentration of tasks that require judgment and complex knowledge. The best preparation for a worklife that puts increasing emphasis on judgment and knowledge is a good education. Providing this preparation is now a grave challenge for America. It is the wellspring of competitive ability in Japan, several Asian developing nations, and many European nations.

EDUCATION: PREPARATION FOR COMPETITIVENESS

During much of the 20th century, the United States had the best educated work force in the world, and American manufacturing was the world's most dynamic and competitive. There is a causal connection between these two, although it is not perfect. At the turn of the century new forms of industrial and work organization, known now as Taylorism and

[1] Richard A. Easterlin, ''A Note on the Evidence of History,' *Education and Economic Development*, C. Arnold Anderson and Mary Jean Bowman (eds.) (Chicago, IL: Aldine Publishing Co., 1965). The figures are reproduced in Nathan Rosenberg, *Technology and American Economic Growth* (New York, NY: Harper & Row Publishers, 1972), p. 38.

[2] The World Bank, *World Development Report 1987* (New York, NY: Oxford University Press, 1987), Pp. 262-263.

[3] Nathan Rosenberg, *Technology and American Economic Growth* (New York, NY: Harper& Row Publishers, 1972), p. 35.

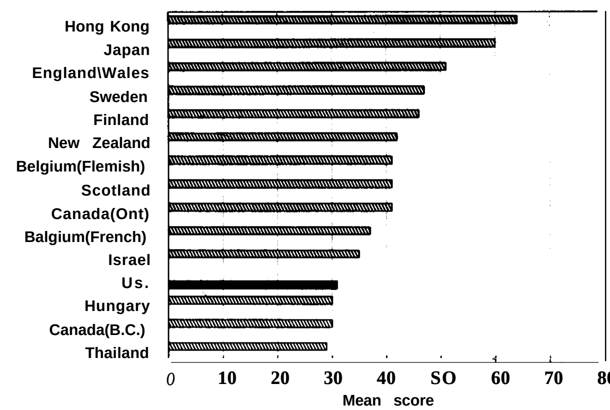
[4] Kazuo Koike, "Human Resource Development and Labor-Management Relations, " *The Political Economy of Japan, Volume 1: The Domestic Transformation,* Kozo Yamamura and Yasukichi Yasuba (eds.) (Stanford, CA: Stanford University Press, 1987), p. 327.

Fordism, tried to reduce jobs to their simplest components, which sometimes also had the effect of reducing the educational demands made on workers. However, many ordinary workers continued to bring ingenuity and creativity to their jobs, and it was this fact, as much as the efficiency of the assembly-line method, that impressed foreign observers about American manufacturing.[5] It is not a coincidence that America is now slipping on both counts, educational performance and manufacturing competitiveness.

American students perform poorly on standardized tests compared with their counterparts in many nations of Asia and Europe. Since the 1970s, they have compared unfavorably with their predecessors in American schools as well. In the mid-1980s American junior high school students ranked 10th in arithmetic, 12th in algebra, and 16th in geometry in a survey of mathematics competence in 20 countries.[6] Twelfth graders, compared with students from 14 other nations, ranked 12th in geometry and 14th in advanced algebra, according 1981-82 survey[7] (figures 4-1 and 4-2). American students scored below students in Canada (Ontario), Scotland, Finland, Sweden, Japan, New Zealand, Belgium, England and Wales, and Israel in functions and calculus. Of the students tested, only those in Hungary and the Canadian province of British Columbia performed worse. Moreover, the survey showed that the performance of American students had worsened in the past two decades. At the time of the frost international mathematics study in the early 1960s, the top 5 percent of American students were performing as well as the top 5 percent anywhere in the world. By the 1981-82 survey, the top 5 percent of American students had sunk to the bottom quarter of the scores of the top 5 percent in other nations.[8] The results are similarly dismal in science. Also, compared with students in many other developed nations, American students are less likely to learn foreign languages.

The deterioration in the performance of American students since the 1960s is just as disturbing as their

Figure 4-l-Twelfth Grade Achievement Scores in Geometry



SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., January 19S7).

poor showing in international comparisons. For many decades, American students scored higher year by year on standardized tests such as the Scholastic Aptitude Test and the Iowa Test of Educational Development. This progress was all the more impressive considering the fact that the American educational system was at the same time reaching more and more people. From 1890 to 1960, time spent in school, daily attendance, and the number of years of schooling completed all increased. For instance, the scores of 12th graders on the Iowa Test of Educational Development rose robustly between 1942 and the mid-1960s, with a dramatic spike in test scores after Sputnik's launch.[9] During about the same period (1941-68), high school graduation in Iowa, where the test was administered, increased from 65 to 88 percent of the relevant population. In the late 1960s, the gains stopped. Scores on many standardized tests began a decline that lasted for over a dozen years. The upturn in test scores in the early 1980s has only partially offset the decline. Young adults who entered the

[5] Jean-Jacques Servan-Schreiber, *The American Challenge* (*New* York, NY: Atheneum, 1969).

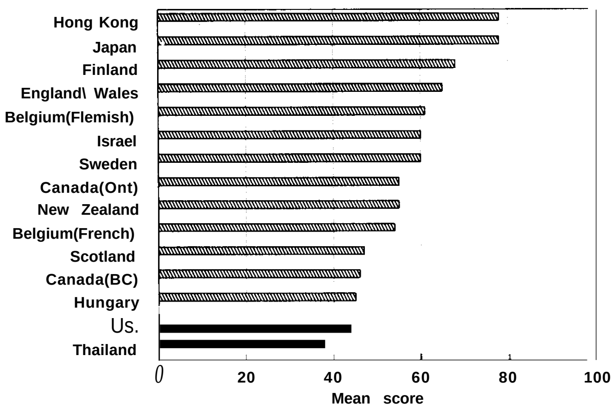
[6] Harold W, Stevenson, "America's Math Problems," *Educational Leadership,* October 1987; and International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co, January 1987).

[7] International Association for the Evaluation of Education Achievement, op. cit.

[8] Ellen Hoffman, "The 'Education Deficit', " *The National Journal,* Mar. 14, *1987.*

[9] John H. Bishop, "Is the Test Score Decline Responsible for the Productivity Growth Decline?" *The American Economic Review,* March 1989.

Figure 4-2-Twelfth Grade Achievement Scores in Advanced Algebra



SOURCE: International Association for the Evaluation of Educational Achievement, *The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective* (Champaign, IL: Stipes Publishing Co., January 19S7).

work force in the 1970s were less well prepared academically than their predecessors, an unprecedented occurrence in America.[10]

THE MANUFACTURING CONNECTION

The strength of a nation's scientific and engineering work force is connected to manufacturing innovation and competitiveness in immediate and obvious ways. The academic accomplishments of shopfloor workers are not so obviously related to competitiveness. When we consider the nature of much factory work—short-cycle repetitive tasks—the relevance of performance in science and mathematics may seem slight.

Yet manufacturing work is changing with advances in technology, and the changes often demand skills that are more in line with academic competence than those required in earlier generations of mass-production factory work. Automated production makes each worker responsible for a larger share of the production process, and creates a greater need for each worker in the system to understand other parts of the system. Emphasis on product quality, often formalized into statistical process control (SPC) procedures, requires workers to have basic skills in reading and math. For example, at a Fujitsu Microelectronics semiconductor plant in San Diego, California, most production jobs require good arithmetic skills, including proficiency with fractions and decimals, to cope with the demands of SPC.[11]

Automated production also requires sound judgment and skill in problem solving. An account of work in a silicon wafer plant in North Carolina states,

> At DNS, the silicon log in its raw state is worth between $2,000 and $5,000. This fact and the cost and expense of the machines employed in sawing make "down time" far more acceptable than scrap. Although the only direct control an operator may have over his or her process is an on/off switch, timely and judicious use of that switch is becoming a high skill.[12]

Programmable automation and/or flexible manufacturing systems require multiple skills, many of them new for production workers. Programmable equipment enables one machine or group of machines to make a much wider range of parts or products than dedicated machines. In the past, workers could learn in a few days or weeks, by watching and working with an experienced worker, how to operate a particular machine. Now, workers must identify more closely with products than with processes or machines, and they are less likely to be buffered from other machines and workers by large stocks of parts and loose schedules. As a result, they must be more familiar with the whole production process and able to operate multifunctional machines. In such a system, operators can no longer rely on learning by example, but instead must be able to read and understand manuals and specifications.[13]

These skills are hard to translate into grade-level equivalents, but training directors of firms that have confronted difficulties with problem-solving ability recognize that a basic proficiency in reading and mathematics is both a good foundation for and an indicator of problem-solving ability. Motorola, for

[10] Ibid., p. 193.

[11] Paul V. Delker, "Worker Training: A Study of Nine Companies, " contract report to OTA, September 1988.

[12] Ibid.

[13] Larry Hirschhorn, "Training and Technology in Context: A Study of Four Companies, " contractor report to OTA, September 1987.

example, determined that workers in its Factories of the Future-fully automated semiconductor production facilities-needed at least sixth grade math and seventh grade reading to cope with demands for mastering different jobs in a rotation system, assuming responsibility for quality control, and participating in problem-solving work teams.

While these requirements are modest, many workers do not possess them. Of a group of 278 Motorola production workers who volunteered for testing, 85 percent were in need of some remedial instruction in order to meet the standard of sixth grade math and seventh grade reading. Most of the people who failed to meet the standard in both reading and math were workers whose native language was not English. Fujitsu's San Diego plant, producing integrated circuits and semiconductors, had the same problem: lack of the basic skills needed for effective participation in quality circles (work groups focused on problem solving). Here, too, the trouble stemmed largely from the fact that many employees, including the Japanese plant managers, were not native English speakers.

This does not mean that basic skills deficiencies in American manufacturing are confined to immigrant populations. Many companies have found that poor basic skills among native workers limit their ability to adopt new technologies. Their experiences are confirmed by results of the National Assessment of Educational Progress' survey of literacy proficiency among young adults aged 21 to 25. Although the NAEP findings show that nearly all young adults are literate in a rudimentary sense, 20 percent of young American adults read no better than a typical eighth grader and 6 percent do no better than the average fourth grader.[14] Moreover, very few young adults were proficient in tasks requiring even a moderate level of complexity. For example, only 9.5 percent of the group, given typical grocery store price information on a unit-cost basis, could select the least expensive of two brands of peanut butter.[15] While it is not focused on the basic skills requirements for work, the NAEP study makes clear that large numbers of young American workers do not come into the workplace with the basic academic skills that employers could expect from their years of formal schooling. Such problems are not confined to new entrants, products of an educational system with slipping standards. They are found also among midcareer and older workers, people whose basic proficiencies were perhaps not strong to begin with, or whose skills have rusted with little use.

With the quality of American academic achievement only now showing signs of rebounding, the prospect is that things will get worse, not better. The growth rate of the labor force is slowing, and a high proportion of the new entrants over the next decade will be from demographic groups (blacks, Hispanics, and immigrants) that traditionally have been educationally disadvantaged. Faced with a declining pool of qualified applicants, employers may not be able to be as selective in their hiring as in the past. Even if educational quality rebounds strongly in the primary and secondary schools, the generation of people that entered the work force in the 1970s, and into the early 1980s, could still depress overall American productivity growth well into the next century, unless employers and public programs take strong measures to help large numbers of workers learn to read, calculate, and communicate better.[16] Well-designed programs can help workers with rusty basic skills improve enough to handle such challenging tasks as statistical quality control and daily maintenance of sophisticated equipment.[17]

In some countries-West Germany is a prime example-a nationwide system for teaching young people technical skills adds a further advantage to that provided by a sound basic education. About two-thirds of Germany's young people go through a 3-year work apprenticeship after finishing compulsory academic schooling at age 16. The vocational training combines classroom studies 1 day a week with organized work the other 4 days, either in a workshop or a regular workplace. To qualify as a craftsman, the trainee has to pass practical tests and a 4-hour written exam. There is evidence that this century-old system (it started with Bismarck) pays off handsomely in productivity, quality, and flexibility in manufacturing.

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[14] Irwin S. Kirsch and Ann Jungeblut, Literacy: *Profiles of America's Young Adults* (Princeton, NJ: Educational Testing Service, 1986), p. 40.

[15] Ibid., p. 34.

[16] OTA is conducting an assessment of 'Worker Training: Implications for U.S. Competitiveness,'' to be completed in 1990. Preliminary results of this assessment indicate that the lack of basic skills among manufacturing workers is a solvable problem, but does require effort and expense.

[17] Delker, op. cit., passim.

A mid- 1980s series of studies comparing matched British and German manufacturing plants-in metal-working, kitchen cabinet manufacture, and garment making-found that the German plants had labor productivity advantages of 60 to 130 percent.[18] In each case, the studies concluded that a major reason for the German advantage was the country's better trained, more highly skilled shopfloor workers. (Technical training of foremen and higher managers was found to be at least as important, in some cases more so.) For example, in the kitchen cabinet plants, nine-tenths of all the German workers on the shopfloor had had 3-year apprenticeships followed by qualifying examinations. At best, one-tenth of production workers in the British plants were so qualified, and several British plants had no workers with similar training. One result: the German workers were adept at using computerized wood-working machinery and a linked system for feeding, unloading, and stacking materials. Fully linked machine lines were hardly to be found in the British plants, one main reason being fear that one of the linked machines would "go wrong" and stop the whole line.

Breakdowns of all kinds of machinery were far more frequent in the British plants-another sign of insufficient worker training. The German operatives routinely clean and maintain their machines, whereas this kind of planned maintenance is virtually unknown in the British plants, according to the study .19 Similarly, in metalworking, breakdowns of machinery-especially of advanced computer, numerically controlled machinery-were a serious, continuing problem in British plants, while the German plants reported only startup problems, never continuous longstanding difficulties.[20]

Apprenticeship training was also credited with helping German shopfloor workers adapt easily to changing requirements. This adaptability is essential to the strategy of the German clothing industry, which concentrates on short runs of high-priced quality products and pays relatively high wages—at least 50 percent higher than wages in the British industry. In the German plants visited for the study, 80 percent of sewing machine operators had completed a full 2-year apprenticeship; no British firm had a single machinist with equivalent training.[21] The German machinists needed only 2 days to reach top-speed production on a new style, and most were able to work on new operations directly from technical sketches. The British machinists typically took several weeks to master a new style, and few could work from technical sketches. Also, quality was apparently much better in the German plants, since the number of quality controllers (passers) was only 1 for 23 machinists, compared to 1 for 7 in Britain. Undoing of faulty work was often observed in the British plants visited, but not once in the German.

It is not the apprenticeship training alone that serves German manufacturing so well. The level of math competence of the average school leaver (age 15 to 16) is substantially higher in Germany than in Britain, and the relative advantage is especially marked for the less academically ambitious students (those most likely to take up operative work) .22 Nor is a public system of vocational training the only way to give production workers the technical skills they need for advanced manufacturing. In Japan, for example, immensely successful international firms such as Toyota or Mitsubishi hire high-school graduates with no special technical training and give them company training. Japan's publicly funded, vocational training institutes typically serve the needs of smaller companies. Many American managers also think they can train production workers adequately, if the workers know how to read, figure, and communicate adequately and have good work habits. The sine qua non is good basic skills.

[18] Productivity was figured on the basis of physical units of production for similar items. The studies were: A. Daly, D.M.W.N. Hitchens, and K. Wagner, "Productivity, Machinery and Skills in a Sample of British and German Manufacturing Plants,' *National Institute Economic Review, February 1985;* Hilary Steedman and Karin Wagner, "A Second Look at Roductivity, Machinery and Skills in Britain and Germany,' *National Institute Economic Review,* November 1987; Hilary Steedman and Karin Wagner, "Productivity, Machinery and Skills: Clothing Manufacture in Britain and Germany, " *National Institute Economic Review, May 1989. See also these* papers by S.J. Rais and Karin Wagner in the National institute *Economic Review* "Some Practical Aspects of Human Capital Investment: Training Standards in Five Occupations in Britain and Germany, '' August 1983; ' 'Schooling Standards in England and Germany: Some Summary Comparisons Bearing on Economic Performance,' May 1985; "Productivity and Management: The Training of Foremen in Britain and Germany," February 1988.

[19] Steeman and Wagner (1987), op. cit., p. 89.

[20] Daly et al., op. cit., p. 55.

[21] Steeman and Wagner (1989), op. cit., p. 49.

[22] Prais and Wagner (1985) and (1988), op. cit.

THE TECHNICAL AND ENGINEERING WORK FORCE

Although good basic skills throughout the work force are fundamental for good manufacturing performance, the defects of ordinary American education and the lack of a robust vocational training system may be more damaging to the nation's technical operatives than to its blue collar workers. Assuming that production workers are competent in reading and simple math, or need no more than brush-up courses, they can be trained for many shopfloor jobs in a matter of weeks. Training of technicians-those who do nonroutine maintenance, programming, and repair of equipment—takes months to years, on top of decent reading and math skills.

One conclusion of the comparative studies of German and British manufacturing plants was that the superior training of foremen in Germany was a key advantage to manufacturers. The German foreman combines technical and managerial skills. He or she supervises workers in the routine care and maintenance of machinery, adapts standard machines to specialized needs, and works with suppliers in developing new machines. The foreman is also responsible for scheduling work (often using computers for the purpose) and ensuring delivery on time.

Most foremen are qualified as *Meister*, or advanced mechanic. Candidates for the *Meister* qualification must first have at least 3 years' full-time work experience following their apprenticeship and qualification as craftsman. Then they take a prescribed set of courses in technical topics, business organization, and training responsibilities, either part-time over 2 or 3 years or full-time for about 9 months. The courses are free but candidates take them on their own time. The written examinations at the end of the course typically take about 17 hours, spread over 3 days. Advanced mechanics in textiles, for example, must pass an exam covering the following subjects:

1. origins and qualities of raw materials and textile products;
2. yarn and thread production;
3. yarn and thread construction;
4. the organizational structure of the firm;
5. the rights and duties of workers;
6. safety rules and first aid;
7. adjustment and operation of fiber preparation machines;
8. adjustment and operation of spinning machines;
9. ability to determine the quality of yarns and threads;
10. maintenance of tools, machines, and equipment;
11. machine parts;
12. electronics;
13. fundamental metalworking; and
14. installation and repair of machines.[23]

This rigorous training and accreditation system for technicians or foremen is routine in Germany, but practically unknown in America. Yet, particularly in automated manufacturing systems, the need is increasing for numbers of people who have the kind of broad mastery described above, people who understand the entire production system and keep it running. Remedying a shortage of these skills is made considerably more difficult when the work force is populated by men and women whose basic educational preparation is poor.

The Engineering and Scientific Work Force

The problem of poor preparation in public schools may turn out to be more acute in the engineering and scientific work force. It takes at least 4 years to produce an engineer, assuming the student has had a solid secondary education. It takes longer to produce most scientists. If because of inadequate basic education the United States cannot keep a healthy flow of scientists into research and development and engineers into R&D and industry, American manufacturing industries will find it increasingly difficult to keep up with, not to mention outperform, industries in other nations.

Several trends are worrisome. First is the number of scientists and engineers in the work force, particularly those employed by industry. The proportion of scientists and engineers in America's work force has remained fairly constant through the last two decades, while in Japan it has risen steadily. Now, Japan has about as many scientists and engineers employed per thousand workers as Amer-

[23] Wayne Brooke Nelson, *Improving Competitiveness in Mature Industries: Lessons From the West German Textile Industry*, Master's Thesis, Massachusetts Institute of Technology, October 1987.

ica, but will soon have significantly more, unless the trends change. Second, it will be hard to spur growth in the number of engineering graduates in America because of three impediments: the poor performance of average American students in science and mathematics in secondary schools; the increasing proportion in the population of America's young people of minorities, who have traditionally done poorly in science and math; and the increased efforts by foreign governments to attract home their own nationals who are graduates of American engineering and science programs.

There are also some more specific problems. Improving productivity and quality in manufacturing means attracting more engineers to manufacturing, and not just to the lucrative electronics industries. Manufacturing engineering has enjoyed much lower status than other engineering specialties, and there are few signs of change. Also, many engineers and scientists are diverted from civilian industries to work on defense technology; it is estimated that 20 percent of U.S. engineers are in defense work.[24] The debate over how much of the engineering and scientific knowledge generated by the DoD spills over into civilian sectors will not be resolved here. However, defense work provides few benefits to most manufacturing industries (aerospace and, to a lesser extent, electronics are where DoD technology has most of its civilian application).

Finally, there are qualitative differences in how Japanese and American engineers spend their days. Japanese companies are structured to do what they are renowned for: make things better, and faster, and less expensively. Accordingly, their use of engineers is well adapted to continual incremental improvement of products and especially manufacturing process. They are not particularly known for coming up with a steady stream of larger technological breakthroughs. American companies, on the other hand, are better known for the stimulation of engineers' creative abilities, but are less effective in day-to-day improvement or in meshing engineers' design with shopfloor production. While both countries are making efforts to reproduce each other's strengths, there is little doubt that the Japanese system has served manufacturing competitiveness better than the American system has in the past few decades.

Numbers and Distribution of Scientists and Engineers

The concentration of scientists and engineers in a nation's work force says much about its capacity for innovation and improved productivity.

Among five industrialized nations-France, West Germany, Japan, the United Kingdom, and the United States—the United States ranks first in the number of scientists and engineers per thousand people in the work force by a small margin (figure 4-3). When it comes to the engineering work force, the United States, with 175 engineers per 10,000 workers in 1984, has a slightly lower concentration than Japan (187 per 10,000 in 1985) or West Germany (194 per 10,000 in 1985), and a higher concentration than the United Kingdom (144 per 10,000 in 1981) or France (105 per 10,000 in 1982).[25]

The number of people entering or graduating from science and engineering programs in this country has responded readily to market forces in the past. The boom in industrial demand for computer scientists, for example, has made computer science the fastest growing field of science at all degree levels.[26] Patricia Flynn, analyzing the shift in industrial composition of the Lowell, Massachusetts area between 1970 and 1982, found that:

> The occupational education network was highly responsive to overall occupational trends in the area and to the particular needs of the high-technology industries. Three-quarters of the occupational education programs, accounting for 85 percent of all of the trained graduates, were "on target" or "reasonably aligned" with occupational employment changes in the Lowell area during the 1970s.[27]

Specifically, Flynn showed how local educational institutions shifted to meet the change in local

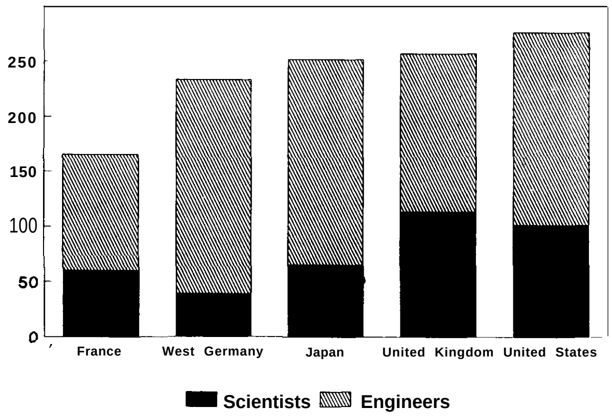
[24] National Academy of Sciences, *The Impact of Defense Spending on Nondefense Engineering Labor Markets (Washington, DC:* National Academy *Press, 1986),* p. *74.*

[25] National Science Foundation, National Science Board, *Science and Engineering indicators-1987,* NSB 87-1 (Washington, DC: U.S. Government Printing Office, Nov. 30, 1987), p. 226, appendix table 3-15.

[26] U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School, OTA-SET-377* (Washington, *DC:* U.S. Government Printing Office, June 1988).

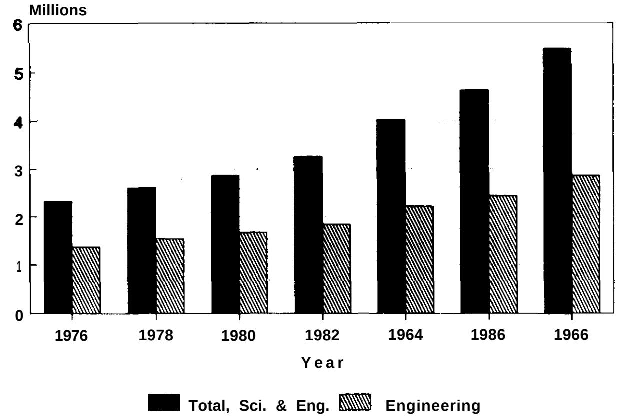
[27] Patricia M. Flynn, Facilitating *Technological Change: The Human Resource Challenge* (Cambridge, MA: Ballinger Publishing Co., 1988), p. 101.

Figure 4-3-Scientists and Engineers per 10,000 Labor Force



SOURCE: National Science Foundation, National Science Board, *Science and Engineering Indicators—1987, NSB87-1* (Washington, DC: U.S. Government Printing Office, Nov. 30, 1987), appendix table 3-15.

Figure M-Employment of Scientists and Engineers



*Estimate.

SOURCE: National Science Foundation, "U.S. Scientists and Engineers: 1988," NSF 88-322, 1988, table 1.

employment patterns and industrial growth. Traditional manufacturing in Lowell was marked by declining average annual employment of 4.0 percent in textiles, 4.9 percent in apparel, and 8.4 percent in leather between 1976 and 1982. At the same time, employment in high-technology sectors took off: annual employment growth in nonelectrical machinery (including computers) was 43.3 percent; in instruments, 23.6 percent; in transportation equipment (mostly aerospace), 7.2 percent; and in electrical and electronic equipment, 7.2 percent.[28] Lowell's educational institutions responded, and the numbers of graduates from high-technology programs grew more than twice as rapidly as the number of graduates from all the other occupational programs.

More generally, engineers and scientists seem to be in adequate supply in the United States-so far. During the past decade there has been healthy growth in the nation's scientific and engineering work force (figure 4-4). Both market forces and government policies have proven effective at drawing people into engineering and science schools, and at attracting people who are qualified to work in engineering from other fields. Federal funding of graduate fellowships has encouraged enrollment in science and engineering and caused some students to shift their postdoctoral plans.[29] Federal science and technology initiatives, such as NASA programs and those at the National Institutes of Health, have also helped to create a healthy job market for graduates. Finally, the boom in microelectronics and computer industries in the 1970s and 1980s also drew many people into science and engineering curricula, especially electronic engineering specialties and computer science. Between 1976 and 1986, for instance, the work force increased just over 2 percent per year, while the number of computer scientists increased nearly 17 percent per year, and the number of electrical engineers increased 7 percent per year (figure 4-5).[30]

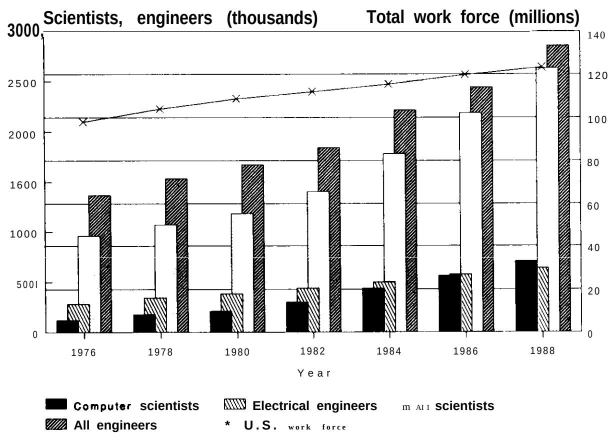
But the trend is a bit bleaker. In the past, engineers and scientists were typically white males. They now make up a shrinking proportion of the pre-college population, which is itself growing smaller. The greatest growth is in the Hispanic population, with a more slowly rising proportion of black people. By the year 2000, 25 percent of the college age population will be black or Hispanic. These two groups, which are more likely to live in poverty, perform less well in school and have had higher dropout rates than white or Asian ethnic groups. It will take greater efforts to prepare and recruit them

28 Ibid., p. 81.

29 Ibid., p. 17.

30 U.S. Department of Labor, *Employment and Earnings*, any issue; and National Science Foundation, *U.S. Scientists and Engineers: 1986*, NSF 87-322 (Washington, DC: U.S. Government Printing Office, 1987).

Figure 4-5-Trends in Science and Engineering Labor, 1976-88



● Estimates, except for total work force.

SOURCES: National Science Foundation, "U.S. Scientists and Engineers: 1988," NSF 88-322, 1988, table 1; and U.S. Department of Labor, Bureau of Labor Statistics, "Employment and Earnings," vol. 36, No. 12, December 1989, table AI.

into the ranks of scientists and engineers. If fewer young people enter engineering and science programs, salaries will be bid up, and employers might face rising costs of securing technical talent. Even with manufacturing employment shrinking, the demand for engineers and scientists might not decline or might even rise, as it takes increasing numbers of scientists and engineers to keep manufacturing competitive. If salaries rise, it will be more expensive to solve technical problems in manufacturing, develop technology, run and adapt equipment. While large companies and high-technology companies will continue to employ engineers and scientists, more small companies will find it hard to afford even one engineer.

To guarantee a steady stream of qualified entrants into college engineering programs, many actions will be needed. One is investment in primary and secondary school programs designed to improve performance in math and science. Actions to attract and retain larger numbers of students into engineering and science would require a substantial commitment of resources, and take many years to yield significant results .31

In the meantime, the Japanese system is already primed to prepare, recruit, and educate engineers. Currently, the concentration of engineers in the Japanese work force is only modestly higher than in the U.S. work force (187 per 10,000 workers in Japan v. 175 per 10,000 in the United States) and their concentration of scientists is much lower (65 per 10,000 in Japan, compared with 101 per 10,000 in the United States) .32 But the educational system of Japan is effectively geared to produce new engineers of a high caliber, while the American system needs substantial improvement before the feed rate into engineering curricula can be stepped up, or even maintained. Over 4 percent of 22-year-old university graduates in Japan hold degrees in engineering, compared with less than 2 percent of 22-year-old college graduates in America. While the absolute numbers are roughly comparable-71,400 new engineering graduates in Japan in 1985, and 77,900 in America-the emphasis of the Japanese system is clear, considering that Japan's population and GNP are about half that of the United States.

Despite its current favorable position, Japan faces its share of problems in engineering. Maintaining strength in manufacturing may prove a bit more difficult than Japan's impressive record would indicate. *Endaka,* or high yen, squeezed Japanese manufacturing, and while industry responded admirably to the challenge, the constraints of being a high-cost nation are beginning to have effects that concern many Japanese observers. Specifically, with the pressure to increase productivity and hold down wages, many newly graduated engineers are opting for careers that offer greater financial rewards than manufacturing. Currently, beginning engineers in manufacturing earn only a bit more than workers with no more than a high school education. In 1987-88, average earnings for male systems engineers 20 to 24 years old were 150,000 yen per month ($1,071 at 140 yen to the dollar); their earnings peaked at 401,400 yen per month ($2,867) for 45 to 49 year-olds (figure 4-6). Prospects for graduating engineers are much more lucrative in Japanese finance, at least for now. The salary of a midcareer (35-year-old) employee in a Japanese bank is the equivalent of $70,000 to $80,000 per year, about

31See U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School,* OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988) for a detailed discussion of these policy options.

32National Science Foundation, National Science Board, *Science and Engineering indicators-1987, op. cit.*

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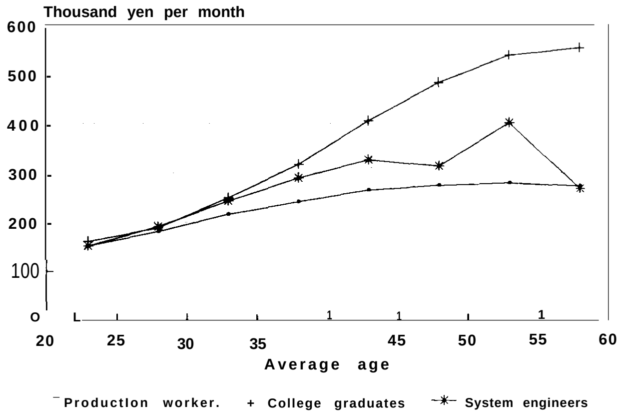
Figure 4-8-Salaries of Engineers and Laborers of Large Establishment= in Japan, 1987-88



SOURCE: Japan Productivity Center, *Practical Handbook of Productivity and Labour Statisitcs '87-'88* (Tokyo, Japan: Japan Productivity Center, 1988), tables 11 and 13.

double the salary of a midcareer manufacturing professional.[33] Little wonder, then, that new engineering graduates should opt for other sectors as they leave school.

The salary differentials-and possibly, the sinking prestige of a career in manufacturing compared with other opportunities-are taking a toll. While 60 percent of graduates from all Japan's engineering universities still entering manufacturing (roughly the same proportion as in the past), the sector is losing its appeal for engineers graduating from the three most prestigious universities (Tokyo University, Tokyo Institute of Technology, and Waseda University). About 80 percent of the engineers from those institutions chose to enter manufacturing in 1982. The proportion has been declining ever since, dropping under 60 percent in 1988. Many of these graduating engineers are being lured into banks and securities companies, where the jobs pay more and the opportunities are regarded as more exciting. A recent survey of electrical engineers showed that younger engineers feel more strongly than other young workers in Japan that they are unable to fully use their talents, and that they cannot do what they're interested in. In addition, like other young workers in Japan, they feel underpaid.[34]

Thus, Japan is not free of difficulties in attracting engineers into manufacturing. However, the superior educational preparation of Japanese students may make Japan's problems easier to solve than ours. Japan's large pool of people who are able to enter science or engineering could be an important safety valve as it enters its own version of uncharted waters. Just as the United States is trying to cope with international competition on an unaccustomed scale, Japan is trying to improve its ability to generate breakthrough advances in science and technology while maintaining its strength in manufacturing process. The new emphasis on innovation probably means that Japan will need many more scientists than it has, and that it will have to spend more on basic research both in industry and in universities-which, compared to American universities, contribute much less to the national stream of technological development and innovation. In addition, some departures from the traditional, seniority-based career paths of Japanese scientists and engineers may be needed.

So far, it is hard to make any case that America doesn't have enough engineers, particularly in manufacturing. There are nearly as many engineers in manufacturing in the United States as in Japan and Germany, and more scientists; there is no artificially created scarcity. The number of people entering or graduating from science and engineering programs seems to respond readily to market forces or at least has done so in the past. The boom in industrial demand for computer scientists, for example, has made computer science the fastest growing field of science at all degree levels. The principal worry for the near future, so far as supply is concerned, is the trend in demographics.

The Functions of Engineers in Japan and America

Japanese and German manufacturing, both renowned for their attention to precision and quality, employ about the same number of engineers per worker as American manufacturing, which no longer has the same reputation. Obviously, it is not just the number of engineers in manufacturing that counts but also how they spend their time.

The Japanese have consistently surpassed their U.S. competitors in manufacturing things reliably, with high precision, and at reasonable costs. In other words, they have devoted more effort than Ameri-

[33] Bob Johnstone, "A Technical Hitch," *Far Eastern Economic Review*, Feb. 16, 1989, p. 49.

[34] Ikutaro Kojima, Yoshio Nishimura, and Toru Suzuki, "The Changing Role of Japan' s EEs," *Electronic Engineering Times, Dec. 5, 1989.*

cans to ironing out the large and small problems of manufacturing. In comparison, American firms have tended to put more emphasis on innovation. Job assignments differ for engineers in America and Japan, as does the relation between design and production engineers.

The careers of Japanese and American engineers in industry differ starting from the time they complete their schooling and join a manufacturing firm. In sharp contrast to American engineers, Japanese engineers are likely to stay with the firm until retirement, and to progress along a fairly predictable path through the hierarchy of the company. Few leave firms and move to another in midcareer. They are more likely to be transferred by their company to an area outside their specialty. The objective is to broaden their job skills and broaden their knowledge of other functions. American engineers are likely to become managers earlier than their Japanese counterparts, and to broaden their knowledge by transferring between companies rather than within them.[35]

About one-third of American engineers work in research and development (940,000 out of a total of 2.8 million, as of 1988).[36] In addition, some 275,000 engineers are involved in the management of R&D. Only about 17 percent of American engineers (495,000 people) work on the shopfloor, in production and inspection.[37] The same pattern, in a more extreme form, prevails in West Germany, where 50 percent of engineers work in R&D, and only 12 percent in manufacturing production and repair.[38] While comparable data are not available for Japan, there are strong indications that the Japanese firm deploys its engineers differently. Japanese engineers are much more likely than their American counterparts to have at least one assignment in a new area to broaden their skills: 62 percent of Japanese engineers report at least one job rotation assignment, compared with only 35 percent of American engineers. Thirty-five percent of Japanese engineers were assigned at some point to production, compared with only 14 percent of American engineers, and 50 percent of Japanese engineers have served one outside assignment in research, design, and development activities, compared with only 14 percent of American engineers.[39]

These standard job rotations afford Japanese engineers the opportunity to acquire a firsthand knowledge of and sensitivity to the problems and constraints of manufacturing. Most observers agree that this understanding explains much of the ability of Japanese manufacturers to bridge design and engineering functions effectively. American engineers, who rotate functions less frequently but change firms far more often, may acquire some understanding of both manufacturing and design, but the record of Japanese and American manufacturing suggests that it is relatively unusual. In Japan, the transfer of research or development to manufacturing is accomplished by transferring people directly, while in the United States one manager is more commonly assigned the responsibility for transferring the knowledge from design teams to production people.[40] The fact that American firms generally make much less effort than Japanese to smooth the differences between product and manufacturing process design and startup shows up in designs that are harder to manufacture, longer startup times, and lower process efficiency.

Japanese engineers are more likely than their American counterparts to take responsibility for making sure their designs are manufacturable, a fact supported by considerable anecdotal evidence. A good example—also typical of the kinds of stories told about interactions of design and manufacturing engineers--comes from an engineer now at Sematech, the U.S. semiconductor manufacturing development consortium. The engineer once worked for a major U.S. semiconductor manufacturer producing 1 megabit DRAMs, and then for Siemens on the Mega Project, the European program to design and manufacture 1M and 4M DRAMs. He recounted the tale of the U.S. fro's unsuccessful attempts to manufacture 1M DRAMs efficiently (e.g., with high yields and low cost). After developing the process

35See Leonard H. Lynn, Henry R. Piehler, and W. Paul Zahray. "Engineering Careers in Japan and the United States: Some Early Findings From an Empirical Study," mimeo, n.d.; and D. Eleanor Westney and Kiyonori Sakakibara, "Designing the Designers," *Technology Review*, April 1986.

36National Science Foundation, *U.S. Scientists and Engineers: 1988*, NSF 88-322, 1988.

37Ibid.

38National Science Foundation, *Scientists and Engineers in Industrialized Countries* (Washington, DC: CIR Staff Paper, November 1986), p. 25.

39Lynn, et al., op. cit. These percentages describe only the job *rotation* experiences of engineers, not their current positions.

40Westney and Sakakibara, op. cit., p. 28.

and prototypes in the laboratory, the company turned the design over to the factory, where manufacturing engineers were unable to get chip yields up to competitive levels. The manufacturing engineers protested that the process had no margin for error, but they did not themselves have the resources or knowledge to do paper analysis and make improvements. The designers, on the other hand, insisted that they had developed a robust and manufacturable process, and shied away from correcting the problems. At Toshiba, where the 1M DRAM process quickly resulted in very high yields, the engineers and scientists who developed the 1M DRAM process and presented the results to the scientific community[41] were also responsible for yield improvement activities.[42]

Case studies also indicate that Japanese firms often have more engineers on the shopfloor than do U.S. firms. In a study of flexible manufacturing systems (FMSs) in the United States and Japan, Jaikumar concluded that the Japanese companies used the systems far more effectively than the American fins. They got their systems up and running in much shorter time and made many more kinds of parts. Further, their machines had far less down time. Much of the difference arose from the ways in which the two countries used their engineers. U.S. managers treated their FMSs inflexibly, like hard-wired equipment, while the Japanese continued to tinker and make incremental improvements.

The adjustments needed to exploit the flexibility of programmable machinery can generally only be done by engineers. In Japanese firms using FMSs, 40 percent of the staff were college-educated engineers, and all the workers were specially trained in the use of computer numerically controlled (CNC) machines. In the U.S. companies, only 8 percent of the workers operating the FMSs were engineers, and fewer than 25 percent of all workers had been trained on CNC machines. In the U.S. firms, the project team of engineers and software specialists who designed the system disbanded and left after they had it debugged and running. In Japan, the engineers who designed the system remained to operate it, making continual programming changes, writing new programs, and staying with it until they achieved untended operation at least 90 percent of the time. In a fully automated FMS metal-cutting operation, Jaikumar found, engineers would outnumber production workers three to one, but the system would require less than half the number of engineers needed in a conventional U.S. system.[43]

[41] Syuso Fujii et al., "A 50 [mu]A Standby 1Mx1/256Kx4 SMOS DRAM With High Speed Sense Amplifier," *IEEE J. Solid-State Circuits,* vol. *SC 21,* October 1986, pp. 643-647.

[42] Personal communication, D. Robyn, S. Baldwin, and A. Buyrn of OTA with Peter Nunan, Sematech, May 10-12, 1989.

[43] Ramchandran Jaikumar, "Postindustrial Manufacturing," *Harvard Business Review,* November-December 1986.

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