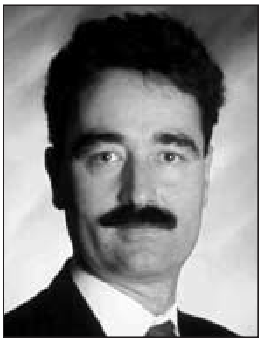
U.S. engineers are now in competition with low-wage engineers in developing countries.

Offshoring and the Future of U.S. Engineering: An Overview



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Engineering as a profession in the United States and other developed nations may soon face a crisis. As a result of sophisticated telecommunications and the digitization of engineering work processes, increasing portions of engineering work can be done without close proximity to particular persons, places, or other processes. In principle at least, this work can be done anywhere in the world that has access to (1) global telecommunications networks and requisite software packages and (2) adequately trained personnel. Undergraduate engineering students in relatively advanced developing nations, such as India and China, follow a curriculum roughly comparable to the one taught in developed nations. Thus, even as barriers to performing conventional engineering work remotely are eroding, a global pool of conventionally trained engineers is growing. This means that U.S. engineers are now in global competition with engineers in developing nations whose wages are 40 to 80 percent lower than ours.

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In this paper, our discussion is limited to work that is relocated but still services markets in developed countries (rather than work done to meet the needs of local markets in developing countries). Offshoring of this work can not only directly replace existing workers, but can also capture jobs that would have been added to the U.S. economy, especially for fast-growing entrepreneurial ventures that must lower cash expenditures and speed up product development. Recent examples include Silicon Valley high-technology start-up companies that establish offshore subsidiaries very early in their life cycles. In these cases, offshoring does not reflect direct job displacement but redirects job growth to lower cost developing nations, at the same time making the start-up more competitive.

Offshoring not only causes direct job displacement, but also redirects job growth to lower cost nations.

Nearly as important as job displacement is the possibility that offshoring could create significant downward pressure on engineering salaries, which is likely if engineers in developed nations are unable to produce significantly greater value than their much lower paid counterparts in developing nations. We are unable to quantify the downward pressure on wages, but there is ample evidence that offshoring combined with technical changes led to stagnant wages for factory workers during the 1990s, and there is a distinct possibility that engineers might experience similarly stagnant wages.

If offshoring continues or even accelerates during the next few years in response to continued pressure to reduce costs, conventionally trained engineers in both large and smaller firms are likely to face sluggish job markets. As a result of these tight labor markets, engineering as an academic discipline is likely to become less attractive to U.S. college students, unless the engineering curriculum changes to address the new reality.

Offshoring Engineering

Twenty years ago, anyone who advocated the offshoring of engineering jobs to developing nations would have been met with derision. Not only were engineers in developing countries considered incapable of performing the work, but they also had limited access to computers and reliable telecommunications infrastructures. In addition, transporting blueprints and data was time consuming, risky, and expensive. As any executive, manager, or research and development (R&D) director at a large or small firm knows, these things are no longer true.

The McKinsey Global Institute (MGI) (2005) recently examined the potential for offshoring globally from developed nations in 10 industries, three of which—automobiles, software, and information technologies (IT) services—are illustrative of the potential of offshoring engineering. In job categories rich in engineers and scientists, such as IT services, MGI calculated that 59 percent of the work could theoretically be offshored. In automotive engineering and R&D, 42 percent of total employment could possibly be offshored. Interestingly, however, they found that fewer than 2,000 automotive engineering and R&D jobs had actually been offshored. MGI attributed the lag to the conservative nature of the industry. However, given the intense pressures on U.S. automobile firms to cut costs and accelerate development, these small numbers may be the beginning of a much larger trend. Among automobile assemblers alone, MGI estimated that 198,000 jobs in developed nations could be offshored in engineering and R&D. Job losses in the United States could be even greater in percentage terms because our manufacturers are also losing market share. But the U.S. auto industry is not alone. In 2005, the Renault-Nissan alliance outsourced IT services contracts worth approximately $600 million to two U.S. firms, Hewlett Packard and Computer Sciences Corporation, and a French firm, Atos (Ovum, 2005). Some of these jobs will certainly go to India and Eastern Europe.

General Motors (GM) is a leader in relocating R&D and certain elements of design. Its offshore centerpiece is a laboratory in Bangalore that employed approximately 240 professionals in 2005 and is expected to employ 400 in the future. The Bangalore laboratory works in partnership with the GM research laboratory in Warren, Michigan. The sophisticated activities in the Indian laboratory are reflected in the skill levels of the persons being recruited. In July 2005, the laboratory was advertising jobs for individuals with master's degrees or, preferably, Ph.D.'s, in aerospace, computer, industrial, mechanical, and software engineering and computer and materials science. In the materials laboratory, GM is searching for people with master's and Ph.D.'s in metallurgy, polymer science, materials science, materials processing, and math-based analysis of materials. In the material process modeling group, work being done by these newly hired engineers will include validating microstructural models, designing high-performance materials, and molecular modeling of nanocomposite/TPO exfoliation and fuel cell membranes (General Motors, 2005). These job descriptions are indicative of the engineering activities major industrial corporations can offshore to India.

GM is not alone, however. General Electric had 1,600 researchers in its research laboratory in Bangalore, India, in 2003 and 3,500 in 2005. A great many other major industrial firms are also hiring technical talent in low-wage nations in a wide variety of engineering disciplines. Even if this trend does not lead to the loss of existing jobs, it will surely produce significant downward pressure on salaries.

Civil Engineering

In May 2004, according to the Bureau of Labor Statistics (BLS), 218,220 civil engineers and 90,000 civil engineering technicians were employed in the U.S. economy (BLS, 2005). Given the importance of construction to the U.S. economy, the unique nature of structures, the need for customizing buildings for specific sites, and the large number of small (less than 50 persons) civil engineering firms, it might seem that civil engineers would be protected from offshoring. However, giant engineering contractors, such as Bechtel Group, Fluor Corporation, Jacobs Engineering Group, Washington Group International (WGI), and others, are already offshoring civil engineering work to lower cost environments. Bechtel has approximately 800 professionals working for its global operations in India, and Fluor has a large engineering operation in the Philippines (Rubin et al., 2004).

Of course, offshoring is not confined to U.S. firms. European civil engineering firms facing the same pressures are also offshoring. For example, Mott McDonald, a British firm, had a unit in Mumbai in 2004 with 850 employees. As such units mature, they will not only increase in size but will also be able to undertake more sophisticated work.

The traditional view has been that offshoring is a "big company" game, but this view is dated. The offshore outsourcing phenomenon is much more common than many believe. BE&K Engineering, a Birmingham, Alabama, firm, does design work in Mumbai and has a unit in Poland (Rubin et al., 2004). And lower costs are not the only, or even the primary concern, for some firms. Harris and Sloan (H&S), an engineering services firm in Davis, California, that employs 27 professionals and is expanding rapidly, subcontracts the services of five civil engineers in India because of space constraints and a shortage of experienced local engineers. In addition, the company realizes a 50 percent savings in cost.

H&S has experienced difficulties with its Indian firm, however, such as high turnover and the inability to manage directly the Indian engineers it trains. The relative lack of control of the outsourced Indian operation has also created problems in terms of wages and benefits. In fact, the company wants to increase wages to raise morale and improve retention. In addition, H&S is considering adding a subsidiary in Vietnam (Harris, 2005). Currently, H&S plans to configure its offshore employee pool to consist of about three engineers and two drafters managed by a high-level "project manager" in the Davis office. As offshoring increases, every group of about 10 will have an offshore manager. H&S is a pioneer in the offshoring and outsourcing trend, but a number of its competitors are also offshoring a portion of their work to Vietnam or China.

Offshoring is no longer a "big company" game.

At a minimum, offshoring dampens upward pressures on wages. By opening an overseas office or contracting work overseas, firms can limit their high-cost domestic head count. In contrast to electrical engineering (EE) and computer science (CS), for which India and China are the destinations of choice, civil engineering firms can also outsource work to the Philippines, Vietnam, and Latin America. For smaller firms that do not require large numbers of workers, other nations can also offer their services.

Because the construction market is so strong in the United States, civil engineering is globalizing less visibly than other branches of engineering. Although changes in the practice of civil engineering differ in some ways from changes in other areas of engineering, the field is being transformed by a combination of design automation software and globalization. Almost as soon as a civil engineering graduate leaves the university, he or she must be able to operate as a "junior project manager" who can deliver creative, cost-effective solutions that include a global component.

Electrical Engineering and Computer Science and Engineering

More U.S. engineers are employed in EE and CS than any other fields of engineering. According to BLS (2005), more than 1.25 million persons were employed in related fields, not including computer programmers, support specialists, systems analysts, database administrators, network and computer systems administrators, network systems and data communications analysts, and other types of computer specialists, who account for another one million jobs. In terms of employment, software and computer engineering is the most important engineering job category, mirroring the technical strength of the U.S. economy.

Until recently, many scholars and most news reporters thought that the activities being offshored would be routine, low-end work, such as data entry and programming—activities that the United States could afford to lose. Unfortunately, this comforting idea is simply not true. Table 1 shows a compilation of jobs described on the websites of five major U.S. electronics and software firms in February 2005. The table is self-explanatory, but note the remarkable number of Ph.D.'s being sought, nearly all of them with at least five years of experience. The job descriptions read exactly like those for technologists being hired in the United States. For example, Cisco India advertised for a master's degree EE&CS graduate with the following credentials in addition to technical knowledge: "Technical, Industry, Business and

TABLE 1 Highest Degree Required in Job Descriptions of Five Multinational Corporations Operating in India and China, February 2005

	None	Technical	Bachelors	Masters	PhD	Total
CISCO						
Shanghai	0	0	17	19	0	36
Beijing	2	0	7	3	0	12
Bangalore	10	0	28	65	0	103
INTEL						
Shanghai	10	9	61	55	9	144
Beijing	1	0	7	6	1	15
Bangalore	11	7	39	112	10	179
HP						
Shanghai	6	2	7	29	1	45
Beijing	5	0	25	28	0	58
Bangalore	15	3	62	42	34	156
MICROSOFT						
Beijing	2	0	0	1	0	3
Bangalore	2	0	13	5	0	20
Hyderabad	17	3	57	14	3	94
ORACLE						
Beijing	0	0	0	2	0	2
Bangalore	9	1	63	16	0	89
Hyderabad	0	0	62	35	13	110

Sources: Adapted from information on the Cisco, Intel, HP, Microsoft, and Oracle websites.

Cross-Functional Knowledge. Partnership. Solve Problems & Make Decisions. Demonstrate Leadership. Establish Plans. Think Globally. Dedication to Customer Success. Innovation and Learning. Acknowledged technical expert on project." This is not an advertisement for a routine, low-level job.

Anecdotal evidence is confirmed by the MGI report (2005), which finds that 60 to 78 percent of engineering and associated middle-level managerial positions in the packaged software industry in developed nations are theoretically offshoreable. The result for IT services is similar—47 to 56 percent of the software and hardware engineering and associated middle-level management jobs are susceptible to offshoring. Analysts working on software/IT architecture and market research are similarly vulnerable (45 to 55 percent). Whether these estimates are off by 10 or even 40 percent is not important. Even low double-digit percentages are certain to be disruptive.

The collapse of the "Internet bubble" in 2000 had a devastating effect on EE&CS on many fronts. Not only have EE&CS departments experienced a drop in enrollment, but employment has not rebounded as well as it has after previous downturns. Students are aware of the threat of offshoring and the increase in EE&CS employment in low-wage, offshore environments.

Start-ups Going Global

Nearly 70 years ago, Karl Compton and other business and engineering leaders in the Boston area created an economic development model in which technological entrepreneurs supported by venture capital would build new firms. A certain portion of these start-ups would grow large and hire large numbers of workers (Hsu and Kenney, 2005). This model reached its apogee in the development of Silicon Valley, which pioneered technologies that transformed the world in which we live. As venture capital funding recovers from the darkest days of 2001, new firms, such as Google, Salesforce.com, and many others, continue to be spawned in Silicon Valley, and some are growing rapidly.

At a recent conference we organized at Stanford, however, presentations by Silicon Valley-based start-ups suggested that a new, global division of labor is emerging. For example, Ketera, a software start-up company headquartered in Silicon Valley, has 75 workers in its Bangalore operation and 150 workers globally. The vice president for engineering at Ketera noted that almost any function currently done by the U.S. team could be offshored, at least, partly. In his view, only customer-facing functions had to remain in the developed country market. He added, perhaps hyperbolically, "I do not see the need for my role as currently described to be U.S.-located in a year's time!" (Shah, 2005). If large numbers of new jobs in small firms continue to be relocated, there may be other ramifications, such as "the relocation of entrepreneurship" per se.

The relocation of new jobs by small firms could lead to the "relocation of entrepreneurship" per se.

A typical start-up company today begins planning for global growth from its inception. In response to pressure from venture capitalists to reduce cash burn rates, start-up companies are creating offshore facilities even before their head counts reach 100. This offshoring decision has two aspects. It lowers the cost of starting a firm and thus encourages entrepreneurship. And, at the very least, it allows a firm to shift mundane work to low-cost locations and reallocate its budgets to new product development.

Take, for example, Tensilica, a Silicon Valley-based start-up firm that relies on intensive, sustained, leading-edge technological innovation by its engineers. During the downturn of 2001 and 2002, even though business prospects slowly improved, the company's engineering budget did not increase because existing products were being improved at the expense of innovation. The solution was to offshore product improvement to India, which the company did in 2004. This change generated savings that enabled more resources to be spent on leading-edge work in the United States (Dixit, 2005).

This example illustrates a second aspect of offshoring—employment growth takes place not only in the United States, but almost immediately offshore as well. In an extreme case, the leadership and marketing team might remain in the United States while most of the employees are located abroad.

Does this extreme represent the future of technology entrepreneurship? This vision may be apocalyptic, but we are convinced that the geographic footprint of start-up firms is in flux. The future cannot be guaranteed, and our mental models of the location of jobs created by the technology entrepreneurship process must be adjusted accordingly.

By creating new value, entrepreneurship can become the antithesis of the zero-sum game.

Responses

Leaders of major U.S. technology firms have cited the appalling state of K–12 education as a major barrier to retaining jobs in the United States. Although we agree that there are serious problems with K–12 education and severe financial difficulties facing publicly supported institutions of higher education, more funding for education will not address the problem of the increasing offshoring of engineering jobs. As the world becomes more globalized, much of the routine, computer-based engineering work can be done remotely, and undergraduate engineering curricula in reputable universities everywhere in the world (many in low-wage nations) are roughly equivalent (and are becoming more so). At the margins, U.S. institutions have more resources and slightly more modern equipment and software, but these amount to no more than a 10 or 20 percent advantage for our undergraduates.

Of course, even within a country, the graduates of the best universities still command a significant premium over graduates from other schools, and this difference crosses borders. At the graduate level, our finest research universities are still superior to universities elsewhere. However, other nations are trying to emulate our success, and they will certainly improve their research capabilities. Thus, simply improving our educational system along the lines of its current operation is not likely to prevent further offshoring.

The career of the engineer of the future is likely to take one of two directions. Engineers employed in organizations will necessarily be required to coordinate projects having global workforces. The critical words in the previous sentence (to which current engineering education pays little attention) are “coordinate” and “global.” A typical U.S. engineer will have to become a project manager early in his or her career and will be coordinating the work of people stationed around the world, either within the parent organization or in contractor organizations.

Entrepreneurship will require engineers to move in a different direction. The heart of entrepreneurship is creating new knowledge and actualizing it in the marketplace. Engineer-entrepreneurs must not only understand how to design good products, but also how to design good business ventures (Hargadon, 2005). Entrepreneurial engineers need not only a rigorous engineering education, but also an understanding of the elements of entrepreneurship. There are advantages to being located in a developed country with sophisticated markets that often set the pace for consumers, and young engineer-entrepreneurs must know how to take advantage of the knowledge in our marketplace. By creating new value, increased entrepreneurship is the antithesis of the zero-sum game.

In the future, most engineers will experience midcareer changes. Thus, the existing model of the engineer who necessarily receives all of her or his training while young, usually soon after high school, must give way to a model of engineers who may choose to enter the field much later in life, perhaps after working in related fields, such as the pure sciences, for several years. New curricula must be developed that allow them to complete their educations over a longer period of time, perhaps while working part time. The University of California, Davis, recently launched a program to train Ph.D. students in the basics of entrepreneurship, not to encourage them to leave graduate programs and academic careers for industry, but to equip them to recognize commercially viable projects in their future academic careers. This kind of flexibility will be necessary to increase U.S. competitiveness.

The licensing of an engineer could also be changed. Perhaps it would be better if licensing were based on a system of regular, midcareer renewals; such licensing systems have already been adopted in nonengineering fields, such as accounting and finance. The advantages of such a system are obvious, especially in light of increasing evidence that the engineers most threatened by foreign competition are not those who are freshly out of college, but those in midcareer who may be replaced by newly trained engineers, either in the United States or Asia. The change is worthy of serious consideration.

Finally, Americans must understand that, just as proximity to sophisticated markets conveys advantages to them, the development of low-cost economies conveys advantages to engineers in other countries. In other words, countries like China and India are rapidly developing markets with unique engineering situations, and American engineers could benefit by becoming familiar with those environments so they can capture value from them, rather than assuming that all high value-added new ideas will necessarily emerge in developed countries. This implies that, at the very least, internships (and perhaps early career paths) should be increasingly global. Some universities have already begun to respond to these challenges. The Asia Technology Initiative at Stanford University, for example, places engineering students in summer internships in Bangalore, Beijing, and Tokyo.

Whether U.S. engineers become entrepreneurs or global project managers, they will need an educational system that provides them with the tools to succeed. An educational system that only provides them with the same skills as their colleagues in China and India will equip them to earn comparable wages (i.e., $6,000 per year plus a bonus for being located in the United States). Thus, engineering education cannot continue as usual. As Table 1 indicates, more of the same education, such as lengthening the curriculum by a year to improve students' technical skills, is unlikely to address the problem of offshoring.

Conclusion

This is not a zero-sum world. If India and China capture more of the engineering value chain, this does not mean the United States must lose. It does mean that we must understand the implications of changed circumstances and experiment with responses. We have focused on the situation in EE&CS and civil engineering, but as GM's Bangalore laboratory demonstrates, all engineering and engineering sciences in the United States may be disrupted. There are ways to address these problems, but fashioning them will require deep study and thought, which are in short supply at the moment.[2] Solutions may vary by industry and discipline, but it would be irresponsible not to prepare for this global shift.

Engineering capabilities, though seemingly concentrated in the education-obsessed nations of East and South Asia, are distributed globally. Traditionally, a small, often elite, group migrated to the United States, but the vast majority of engineers or potential engineers remained in their homelands, unable or unwilling to move to where the job opportunities were. This labor mobility barrier protected U.S. engineers from competition and allowed them to demand high wages. Nevertheless, over the last three decades, the internal U.S. engineering workforce has become increasingly internationalized.

Although the labor mobility barrier persists, decreases in the cost of telecommunication, the increase in bandwidth, the ubiquity of the Internet, and the adoption of standardized software, combined with increased comfort with offshoring and outsourcing, is changing the global engineering labor market. Lower cost, similarly skilled engineers are now available worldwide.

For the most highly educated, most brilliant engineers, offshoring is likely to have little, if any impact. There will always be positions for them, they will continue to be rewarded for the enormous value they create, and the nation where they are based will be rewarded in taxes and profits. Our concern is with the 90 percent of engineers who will be pushed into international competition, just as U.S. factory workers were more than two decades ago.

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For engineers being trained today, this new reality is becoming increasingly evident. Their response is difficult to predict, but as the cost-benefit equation shifts, and if engineering education only provides them with the same skills as others in the global economy, many are likely to pursue other fields of learning. This would be unfortunate, however, because enormous opportunities are being created for technically skilled graduates capable of understanding and operating in global

[2] A forthcoming report by the Association of Computing Machinery Job Migration Task Force, which was appointed to examine these issues and recommend responses, will provide a detailed analysis for the changing location of the workforce for software. The report is expected to be published in late 2005.

networks or with the entrepreneurial skills to discover new opportunities and pull together the resources and teams capable of actualizing them.

Protectionism and anti-offshoring agitation are likely to be little more than rearguard actions, which may be justified only if more long-term responses are simultaneously put in place. But given the history of U.S. responses to threats from imports and offshoring, protection is likely to become permanent and a substitute for real change. In the long run, the "protected" industrial sector will eventually collapse anyhow, as happened in consumer electronics, integrated steel production, and, quite possibly, automobiles. Engineering is too important a contributor to our economy to entrust its future solely to market forces in the belief that a positive outcome will result. A more rational, positive response is to try to determine the skills future U.S. engineers will need and then make changes to provide them. Only then will U.S. engineers be capable of creating a new reality.

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