The Impact of Offshoring on the Engineering Profession

by

Robert P. Morgan*

Professor Emeritus of
Technology and Human Affairs
Washington University in St. Louis

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*Note: Please send feedback, comments, suggestions concerning this paper to
Robert P. Morgan, 1025 N. George Mason Drive, Arlington, VA 22205
Phone and Fax: 703-465-1245; E-mail: rpmtha@comcast.net

Inquiries concerning the use of this paper should be made to Proctor Reid,
National Academy of Engineering, 500 Fifth Street NW, Washington, DC 20001
Phone: 202-334-2815; E-mail: preid@nae.edu

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I. INTRODUCTION

A. Prelude

In the fall of 2003, the National Academy of Engineering (NAE) commissioned me to prepare a background paper on the Global Outsourcing of Engineering Jobs[1]. The paper summarized the growing evidence of and increasing concern in some circles with this phenomenon which had only recently become quite visible. On October 10, 2003, I presented my findings to the NAE Program Committee and highlighted several recommendations for further NAE attention, the first of which was to hold a Workshop to learn more about this rapidly growing phenomenon.

My own reaction when I first read about the offshoring of service jobs in computers and information technology (IT) was to feel instinctively that the phenomenon was real and could have important implications for the broader engineering profession as well. My own background and interests alerted me to possible impacts and implications for engineering education and for the ability of the engineering profession to remain an attractive career choice for young people. Hence, the 2003 background paper followed.

The paper was arguably the first to attempt to look at outsourcing as it might affect the entire field of engineering. It highlighted the lack of data and analyses to quantify the scope of this problem. Since then, there have been some important contributions to try to improve our understanding of outsourcing, including the book, *Outsourcing America*[2] by Ron and Anil Hira and reports by the U.S. General Accountability Office (GAO)[3] and the National Academy of Public Administration (NAPA)[4]. However, there remains a great deal that is unknown concerning the offshoring of engineering jobs and its impact on the engineering workforce and profession. Hopefully, our knowledge and understanding will be greatly enhanced by the forthcoming National Academy of Engineering Workshop on Offshoring of Engineering to be held on October 24–25, 2006.

B. Objectives of This Paper

The movement of U.S. engineering jobs to other countries may or may not be affecting the attractiveness of engineering as a profession of choice, the status, wages and job security of practicing engineers, and the extent to which engineers derive satisfaction and enjoyment from their work. By reviewing any available relevant materials and obtaining views of knowledgeable individuals, I hoped to be able to lay out, primarily qualitatively, what is known and unknown about the impact of offshoring on the engineering profession in its entirety.

The specific tasks I have undertaken include the following:

1. Review readily available on-line and print materials on offshore outsourcing and its impact on the engineering profession.

2. Review any available material on the status of the engineering profession and the level of job satisfaction in engineering over the past 20 or 30 years to discover any changes that may have occurred.

3. Conduct a small number of telephone or in-person interviews with persons who may be able to shed light on the impact of offshore outsourcing on the engineering profession, including professional society officials, NAE members, working engineers, and academics.

4. Attempt to elicit additional views on these matters with a brief E-mail probe to selected individuals.

5. Synthesize my findings into a paper that will lay out, primarily qualitatively, what is known and unknown about the impact of offshoring on the U.S. engineering profession.

C. Summary of Information Gathering Activities

I sought information for this paper via the following routes:

1. I performed online web searches using a variety of combinations, including "offshoring + engineering profession"; "outsourcing + engineering profession"; "engineering + job satisfaction"; "job satisfaction + professions"; "engineering profession".

2. I sent out initial inquiries, including a statement of what I was trying to accomplish to about 17 individuals, primarily by E-mail, almost all of whom were in academia or government. As of July 17, eleven individuals had responded and in some cases there had been follow-up telephone conversations. Their responses provided or identified reports, papers, surveys and other materials relevant to my inquiry.

3. In response to my initial inquiry, William Salmon, Interim Executive Director of the American Association of Engineering Universities (AAES), offered to forward my inquiry with his endorsement to his mailing list of contacts in U.S. engineering societies. I gratefully accepted. His letter went to roughly 70 organizations. As of July 17, the response had been small (only four that I know of) but resulted in significant information.

4. I have also made use of materials I have collected in connection with my 2003 NAE outsourcing paper to identify possible sources of newer information.

5. My initial wave of inquiries led to further contacts. Those contacts plus a small number of earlier sources were generous in providing additional information.

6. During the period of this study, from June through September 2006, I assembled over 100 “pieces” of information, either in print or in a computer file. And it keeps coming in.

D. How Things Have Changed Since 2003

Based upon the work I have done on this project to date, the following appear to have occurred over the past two or three years.

1. Offshoring of engineering jobs has continued to grow, both in extent and acceptability by industry and government. It appears to be becoming more common as an element of doing business in the 21st century “Flat World” of Thomas Friedman[5] and as an inevitable by-product of globalization and high-speed, high-capacity communication networks. In fact, in an Op Ed piece in the May 18, 2006, *New York Times* in which Friedman highlights new models for doing business in a global economy, he moves beyond one-way outsourcing or offshoring to the following: “It’s called “around sourcing” because there is no more “out” anymore. Out is over”.[6]

2. There continues to be concern on the part of U.S. working engineers and within the U.S. engineering profession about the impact of offshoring on employment, job security, and the attractiveness of engineering as a career for young people. This situation persists in spite of very recent improvement in unemployment statistics and recovery in engineering bachelor’s degree enrollments. Of particular concern is the impact on mid-career engineers who were affected negatively since the turn of the century. A 2004 IEEE-USA unemployment survey revealed that the transfer of their jobs offshore was cited by IEEE members who were unemployed as the second highest cause of unemployment, at 15% compared with 62% of those unemployed who cited a business downturn as the cause of their being laid off.[7] And although unemployment rates of electrical engineers had declined by the first quarter of 2005 from a record high of 6.3% in 2003 to 2.1%, total employment declined from 363,000 in 2003 to 335,000 in March of 2005, indicating that a large number of engineers may be exiting the profession.[8] Other engineering disciplines may be affected as well. In a poll of membership in ASME to determine priority issues for ASME’s public policy agenda for 2005-2006, the category “Offshore Outsourcing of Engineering/Manufacturing Jobs” received 862 votes from 1322 participants, placing it fourth behind Energy Policy and two other issues.[9]

3. There have been a number of studies, papers, and reports that deal with various aspects of offshoring. Many are listed in the excellent bibliography for the forthcoming NAE Offshoring Workshop. For a summary of data that are needed and research that might be performed to illuminate various aspects of offshoring, the NAPA, GAO, and MIT Services Offshoring Working Group reports are comprehensive and recent (2006),[10] although not specifically focused solely on engineering. Particular attention in the NAE Workshop will be given to offshoring in six specific industry areas that have been the subject of study for some time by the University-Industry Centers established with Alfred P. Sloan Foundation support. These areas, which all have substantial engineering involvement, are software, automobiles, construction, semiconductors, pharmaceuticals, and new and non-traditional engineering fields. Six papers that have been commissioned by the NAE should provide new, detailed information on and insights into offshoring within these six areas.

E. Focusing This Paper

Given the overall structure of the NAE Workshop and the substantial body of information of varying degrees of quality and relevance to the topic of offshoring of engineering jobs, it was decided to focus this paper primarily on one aspect of the NAE Workshop, namely the impact of offshoring of jobs on the engineering workforce and the profession as a whole. This topic will constitute a portion of the program on the first afternoon of the Workshop. The impetus for addressing this area came in part from an article in the summer 2005 issue of *The Bent* of Tau Beta Pi by Samuel Florman, an NAE and Project Steering Committee Member, entitled "My Profession and My Nation: A Worrisome Confrontation."[11] According to Mr. Florman: "With the coming of *globalization*, the climate for American engineers has turned ominously inhospitable. Specifically, the outsourcing of technological work requires American engineers to compete with skilled professionals abroad whose salaries are very low……. It is difficult to prove statistically that globalization is jeopardizing the well-being of American engineers. Yet sudden spurts in unemployment …. plus anecdotal evidence, have created widespread feelings of anxiety and anger."[12]

To focus this paper, I have been seeking answers to the following specific questions:

1. How many U.S. engineers have been negatively affected by offshoring during the past five years or so? Variables of interest include loss of jobs, reduction in salaries, and loss of job security. Have older engineers been affected disproportionately? What about years of service? Salary level?

2. What are U.S. engineers who lost their jobs doing now? Are they employed? Are they still in engineering? How do their wages and benefits before and after they were affected by offshoring compare?

3. Has the offshoring of U.S. engineering jobs, either real or perceived, made a career in engineering for young people more or less attractive? Why?

4. Does the engineering profession provide adequate support for its members who are affected negatively by offshoring? If not, what additional support should be provided?

5. Are job retraining programs and trade adjustment assistance for U.S. engineers negatively affected by offshoring adequate? Are they available? If not, what additional support should be provided?

6. Is offshoring of engineering work contributing or does it have the potential to contribute to a significant loss of in-country R&D/S&T capability? Might such a loss negatively affect the ability of the U.S. to produce things and provide services, thereby further weakening the U.S. trade situation?

7. Has the morale of the U.S. engineering profession been negatively affected by offshoring? Will the psychological and emotional effects of offshoring on the profession contribute to a loss of needed engineering workforce capacity and capability in the future?[13]

8. Has the overall satisfaction and enjoyment that is derived by U.S. engineers from their jobs been affected by offshoring? If yes, in what way?

9. (*What follows are Sam Florman's words. They incorporate elements of 1, 3, and 5 above (at least) but are said in a much more compelling way:* "Is the "problem" mainly the grousing of a few malcontents who have lost their jobs? Or is it something far more complex and threatening, worthy of thought and action?

II. SETTING THE CONTEXT: THE ENGINEERING WORKFORCE AND PROFESSION

I have chosen to devote a significant amount of attention in this paper to describing key elements of the U.S. engineering workforce and profession. These elements provide the background and context which are necessary to understand and arrive at informed judgments about the impact of offshoring of engineering jobs. One would think that there is assembled and available, in one convenient source or within one organization, current information and analyses that describe these contextual dimensions of engineering in recent years and that monitor changes that may be occurring on a timely basis. My experience indicates otherwise. Engineering is an under-examined, under-scrutinized and poorly understood profession. Furthermore, with a few notable exceptions, there have been no seminal attempts, ongoing or otherwise, to look at the engineering profession as a whole.[14]

A. The Engineering Workforce Project. The IT and STEM Workforce Data Projects. S&E Indicators

1. The Engineering Workforce Project.

The National Science Foundation's Engineering Workforce Project (EWP), which essentially ended in the 1990s, summarized and analyzed the wealth of information that is available in NSF's SESTAT[15] database. A 2004 EWP Report contains the following two excerpts:[16]

> "As of 1999, approximately 2.8 million people in the United States had an engineering degree at the baccalaureate level or above. Some of these engineering graduates—about 1.3 million of them—were employed as engineers. At the same time, nearly a million were applying their engineering knowledge and skills to solve problems in other technical areas or were engaged in a surprising variety of non-engineering careers."[17]

> "The majority of engineering graduates (57%) are employed in some engineering specialty. However, the data strikingly show that they re progressively less likely to be employed in engineering positions as they mature."[18]

A 1998 paper by LeBold, Burton, and Parker, which summarizes some findings from the EWP, contains a section on engineering workforce changes since 1965. The changes indicated in this section utilize data from 1965 through 1993. It states:[19] "…(E)ngineering continues to be one of the few professions in which entry requires only the bachelor's degree. … (O)nly about half of the working engineers belong to a professional society,… a slight decline since 1965. …. About one-third have an engineering license or certification, a slight increase since 1965…. The major engineering fields, civil, chemical, electrical, and mechanical engineering still are dominant fields numerically. But they have given birth to many new engineering fields: construction, environmental, and surveying in civil engineering; software and information systems in electrical engineering; and aeronautical, industrial, and manufacturing in mechanical engineering….. In 1965, only 17 percent of (engineers) fathers and nine percent of their mothers had college degrees. In 1993, 47 percent of their fathers and 41 percent of their mothers had earned college degrees."

I had a recent E-mail exchange with Linda Parker who, with Lawrence Burton, created, promoted, nurtured, and was heavily involved in the work of the Engineering Workforce Project. Here are two excerpts from her E-mail:[20]

> "The S&E workforce is so dynamic and flexible that spot shortages in specific fine-field occupations can take place, but most jobs aren't sufficiently rigid technically that no one without degree programs matching the occupation name could do the work and so would be hired. In our big report on the engineering profession (people doing engineering), … the percentage (of) people whose highest engineering degree field matched the occupation was less than 50% in quite a few occupations and …. only some—not remotely all—of the remaining people in those occupations had any engineering degree, with each occupation having at least some it not a substantial percentage of the workers not having any degree. The holes get filled in with people with the relevant skills and, ever since the end of the Second World War, there has been a constant stream of people from countries in conflict who have moved to the U.S. and in many cases become citizens doing valuable jobs."

Although some aspects of the work of the Engineering Workforce Project (EWP) have been picked up by the STEM Workforce Data Project, the sharp focus on engineering in all of its ramifications that the EWP provided is missing. In Linda Parker's words: "What a huge loss for the engineering world."[21]

2. The IT and STEM Workforce Data Projects.

In some respects, the successor to the Engineering Workforce Project is the STEM Workforce Data Project, being carried out under the auspices of the Commission on Professionals in Science and Technology (CPST). This project, which follows on the heels of an earlier CPST effort on the IT Workforce, looks not only at engineering but other science, technology and mathematics professions. The STEM Workforce Data Project, as well as its predecessor, is co-directed by Richard Ellis, principal investigator, who has also performed similar analyses in past years for the Engineering Workforce Commission (EWC) and IEEE.

a. The IT Workforce Data Project.

On August 28, 2003, the last report of the IT Workforce Data Project was released, entitled "The Outlook in 2003 for Information Technology Workers in the USA."[22] The results of the report were highlighted as follows:[23]

"Conditions in U.S. information technology (IT) have changed significantly in recent years: The "boom" has ended and demand for IT specialists is relatively weak. Still, some observers maintain that the United States lacks an adequate IT workforce and policymakers continue to debate the merits of supplementing the supply of IT people with foreign high-tech specialists using temporary work visas, as well as developing policies to support outsourcing of IT work to locations in other countries. The purpose of the IT Workforce Data Project series is to identify and disseminate trustworthy statistics on information technology workers in the United States. Credible information will enable policymakers and other stakeholders to adequately assess need when formulating their views.

Recession Effects. In the last twenty years, the number of U.S. jobs in core IT occupations have more than tripled, from 719,000 in 1983 to 2,498,000 at the sector's peak in 2000. About 150,000 of these positions were lost in 2001 and 2002, almost two thirds of them in programming. Unemployment in core IT professions began to rise before the sector's peak years, going from 1.2 to 1.9 percent between 1997 and 1999. Levels of joblessness shot up to 3.6 percent in 2001, 4.3 percent in 2002, and an average of 5.9 percent for the first two quarters of 2003.

Changes in Education. In years past, a majority of those employed in IT jobs were trained for other professions, typically engineering or other scientific fields. The number of new bachelor's students in computer science jumped 40 percent in 1995–96, after a 5 percent increase the previous year, leading to record numbers of new degrees in IT disciplines through 2001–2002 academic year, according to the Computing Research Association. Federal data from the National Center for Education Statistics confirm that major increases in IT degree awards have been recorded. However, the market for jobs for these new graduates is now very poor.

Immigration Trends. The rates of foreign-born core IT workers doubled from about a tenth of this labor force in 1994 to over a fifth of it in 2001. Immigrants in the IT workforce are both younger and better educated than their native counterparts: In 2002, 53.3 percent of the immigrants with core IT jobs were under the age of 35, compared to just 41.0 percent of the natives. 41.1 percent of the immigrants had graduate degrees, compared to 16.2 percent of the natives. The increase between 1994 and 2002 in foreign participation in U.S. IT labor markets was facilitated by legislation that expanded the annual number of allowable admissions of persons with H-1B temporary worker 's visas. These higher caps are due to expire this fall. Between the late 1980s and 2002 the use of L visas more than tripled. These are intended to help multinational businesses by supporting transfers of executives and managers to locations in the U.S. for up to seven years, and transfers of "specialized knowledge" workers for up to five years. A recent Congressional Research Service report acknowledges that firms may be using these visas to transfer rank-and-file employees.

Outsourcing Trends. The following statistics relate to a growing tendency for firms to ship technical work overseas. The U.S. Department of Commerce reports that these transactions in import services have grown from under $300 million in 1995 to over $1.2 billion in 2001. A McKinsey & Co. estimate that "projected software and service exports to the United States in 2003-04 are expected to come in at $8.5 billion" from just India alone. A widely cited Forrester Research report released in November 2002 predicts that 3.3 million white-collar jobs, worth $136 billion in U.S. wages, will be shifted out of the nation by the end of 2015. This forecast includes 473,000 IT positions, over and above those already lost to earlier movements of this kind. Dwarfing the Forrester numbers, in July 2003, Gartner Inc. estimated that 10 percent of all U.S. professional jobs in IT services firms would be transferred overseas by the end of 2004, along with five percent of the IT positions in other types of organizations.

Projected Changes in Demand. Projections assume a steady continuation of long-term trends. 2001 data from the Bureau of Labor Statistics is bullish on prospects for careers in core IT data professions. Data from the Bureau's ongoing survey of business establishments yield an estimate of 3,276,000 IT jobs in the baseline year of 2000. Projected 2010 employment for the same set of occupations is 5,432,000. Other assessments of future demand and the growth of the industry from the RAND Corporation and the National Science Board are also positive, but the views of practitioners are not so sanguine. Many prominent high tech workers doubt that the United States can be a cost-competitive source of labor in a global employment market and while IT could be dominated by North American multinational businesses, they may not be particularly dependent on North American technical talent. The United States does not lack sufficient numbers of capable people who would like to work in IT, but it does lack sufficient incentives for able people to choose scientific and technical careers."

Some Comments on the IT Workforce Data Project. Although some changes may have occurred in the aspects of the IT Workforce covered in the "2003 Outlook," particularly projections and trends, the work, quoted in some detail above, exemplifies the kind of careful analysis of available data that needs to be conducted on an ongoing basis for the engineering workforce, utilizing data for the most current year for which data becomes available. Surveys conducted by engineering professional associations can also provide valuable information and insights.

b. The STEM Workforce Data Project: Twenty Years of Scientific and Technical Employment.[24]

Abstract. "Time series data from the U.S. Bureau of Labor Statistics (BLS) for employment by occupation from 1983 through 2002 can be used to document substantial growth in the overall numbers of persons in the United States with scientific, technological, engineering and mathematical (STEM) jobs. A pause in this general trend of growth occurred during the business recession of the early 1990s, and declines in employment also affected many STEM occupations in 2002. Much of the growth was due to the recent boom in the computer and telecommunication industries. Other sectors of STEM employment did not do as well. The number of jobs in some occupations declined over the 20-year period, while growth in other occupations did not keep up with general increases in the overall size of the U.S. labor force. This report presents this information. It also examines recent employment data for 2003. A separate data archive at www.cpst.org includes both the source statistics from BLS, and more detailed versions of the STEM tabulations presented here."

This report does contain tables that break down annual employment totals by broad STEM occupations and selected occupations. Considerable attention is devoted to explaining what is included in various occupational categories. This is particularly important because in 2003, the BLS changed the definition (i.e. the occupational codes) of certain categories. One of great importance to engineering is the movement of jobs that were classified as being within electrical and computer hardware engineering and engineering technology in 2002 into new categories of computer jobs in 2003.[25] This may account in part for the result that 2003 employment in electrical and computer hardware engineering and engineering technology is reported as 477,000 less than in 2002. BLS was in the process of generating detailed data on the effect of changing codes. I did not check to see whether that information is available. The categorization and re-categorization of electrical engineers vs. computer professionals has bedeviled the engineering profession for at least a generation.

Exhibit 2 of the report tabulates employed persons in broad STEM occupations for the period 1983–2002, during which time occupational categories were presumably fairly consistent. For all engineers, the number employed rises from 1.602 million in 1983and then, after a slight reduction, resumes rising through 1990. It then falls for the next three years and in 1994 starts a steady rise until it peaks in 2000 at 2.200 million employed, an increase from 1983 of about 25%. Then for 1991 and 1992 it falls.

Data is also presented on employment by engineering discipline. Most of these disciplines, especially the major ones, show decreases in numbers from 2001 to 2002. The report singles out several categories within engineering and engineering related professions as having growth or shrinkage over the 20-year study period. Drafting occupations, nuclear engineers, petroleum engineers, and surveyors and mapping scientists are all in the "shrinking" category whereas electrical and electronic engineering technicians grow by 187% through 2001 and then fall back appreciably in 2002.

The report tabulates results for 2003 separately, in part because of changes in occupational categories discussed above. The total employed for engineers is 1.879 million compared with 2.090 million in 2002. Part of the difference may be due to the creation of a new category for "engineering managers," with 0.077 million in 2003. In that year, 10.4% of all employed engineers were women, 3.3% were Blacks, 10.4% were Asians, and 4.0% were Hispanics. As a percentage of the total labor force (both those employed and unemployed) 4.2% were not employed.[26]

In the press release entitled "Scientific and Engineering Employment Grows Faster Than Total Labor Force Over Last Two Decades" that announced the release of the report, most of the highlights describe trends for the entire STEM workforce, not only for engineers. Some highlights relevant to engineering were as follows: "Computer systems analyst and scientist occupations grew faster than any other STEM occupation, with a growth rate of 665% from 276,000 in 1983 to a peak of 1.8 million in 2001….. Occupations with considerable shrinking employment included mining engineering which shrank from 8,000 in 1983 to 2,000 at its trough in 2002, only 25% of its original size. Other occupations with significant losses of jobs include agricultural engineers, surveyors and mapping scientists. Petroleum engineers, nuclear engineers, and drafting occupations."[27]

Things to Come. What would be particularly useful for informing the offshoring debate would be engineering employment data for 2004 and 2005. A report with 2004 data from the STEM Workforce Data Project should be out soon.

c. A Half-Century Snapshot of the STEM Workforce, 1950 to 2000

A longer-term historical perspective on how the STEM workforce fared during the last half-century is provided by an August, 2006 White Paper prepared for the STEM Workforce Data Project by B. Lindsay Lowell and Mark Regets.[28] An excerpt from the Abstract is as follows:

> "This report documents the significant growth of the STEM workforce and looks at the major STEM occupational groups from 1950 to 2000. While the total labor force grew 130 percent to 139 million during this period, the STEM workforce grew 669 percent to reach 6.9 million. The report shows the total number of STEM workers, as well as the percentage of those who are women, minorities and foreign born. The growth of the STEM workforce has been greater than that of other major professional occupations since the 1950s. Women increased from 8 percent of STEM workers in 1950 to 26 percent in 2000. Despite these strong gains, they remain underrepresented in STEM relative to their 47 percent share of all U.S. workers. Minorities in STEM occupations were too few in number to be reliably counted in Census data until about 1970. They continue to be underrepresented in STEM jobs, with the exception of Asians who in 2000 made up 10 percent of STEM workers and 4 percent of the total U.S. labor force. Foreign-born STEM workers made significant gains across time, especially in the 1990s. During that decade they contributed one third of STEM employment growth and their representation in the life and physical sciences doubled to roughly 24 percent of each workforce. Among foreign-born STEM workers, the shift has been to those from Asian origins. In 1970, 54 percent of foreign-born workers were from Europe; by 2000 about 59 percent were from Asia."[29]

The results of the report indicate the following about engineering and engineering-related professions. From 1950 to 2000 the "engineering" workforce grew 324% to 1.82 million while "engineering technicians" grew 1929% to 0.54 million. The percentage growth for the engineering workforce tended to slow down with time. From 1990 to 2000, it only grew from 1.781 million to 1.820 million, or 2.2%. However, some of this may be attributed to the phenomenal growth of the "mathematics and information technology" category which includes computer professions. There were extraordinary increases from 1980 to 1990 and from 1990 to 2000 of 226% and 224% respectively, with a gain of 2.62 million jobs over the 20 year period, ending at 3.267 million in 2000. The meteoric rise of computer occupations knocked engineering off its statistical perch as the most populous STEM profession. However, in 2000, engineering still accounted for 26.5% of all STEM workers.[30]

Although women have made some gains in engineering, growing from 1.8% in 1950 to 10.6% in 2002, they remain underrepresented compared with all other STEM occupational groupings.[31] Of three minority groupings, the largest gains from 1950 to 2000 were for Asians (from 1.4% to 8.9%), followed by Blacks (1.1% to 4.0%) and Hispanics (1.4% to 3.9%).[32] These minorities fair better in most other STEM occupational groupings. By 2000, 16.1% of workers in engineering were foreign born, rising from 7.3% in 1950.[33] In 1950, 54.5% of all foreign-born workers in engineering were from Europe compared with 24.2% from Asia. By 2000, these positions had reversed, with 20.9% from Europe and 57.8% from Asia.[34]

3. 2006 *Science and Engineering Indicators*

I do not have the time and resources to examine and analyze the 2006 NSF *Science and Engineering Indicators* in any detail. However, there are two figures in that voluminous compilation that indicate relatively slow growth for engineering employment and job openings in the future.[35] These projections are from the Bureau of Labor Statistics and are based on the projected growth of specific industries. Projections for employment and job openings in engineering are below average for all occupations; in fact they are the lowest of all occupational groupings. Engineering employment growth is projected as 7.3% over a 10-year period from 2002-2012. Job openings in engineering are projected to grow by 29% over the same period. Older people are more subject to layoffs.[36]

B. Engineering: A Proud, Porous and Perplexing Profession

In this section, I will give my own perceptions of the engineering profession, based upon having observed it for more than 40 years with one foot inside and one foot outside it. For starters, I will not provide the standard dictionary or current professional organizational definitions of engineering, assuming one could ever find one that people could agree on. Instead, here is my favorite definition, as I presented it at a 1976 meeting of the Board of Directors of the Engineers Council for Professional Development (ECPD), the predecessor organization to ABET, the organization that currently accredits engineering curricula:

> "Engineering is the profession in which a knowledge of the mathematical, natural, social and policy sciences gained by study, experience, and practice is applied with sensitivity and judgment to develop ways to utilize, economically and ecologically, the materials and forces of nature for the benefit of all persons and to assess the impacts of such utilization upon the individual and society."

The engineering profession has certain characteristics that are worth highlighting here. Unlike medicine or law, you can enter the profession with only a bachelor's degree or in some cases, even less formal education. It is a porous profession, as the Engineering Workforce Project has pointed out, with considerable inflow by individuals of many backgrounds and lots of outflow. A significant percentage of engineers go into management and a variety of other non-technical positions; as such one can argue about whether they are still practicing engineering. A smaller percentage of engineers practice engineering for the duration of their careers than do physicians and lawyers.

The engineering profession has always had some significant schisms. It is fractured by discipline, by whether some form of professional licensure or professional certification should be required, and by whether engineers owe their allegiances primarily to companies and management, to their professional peers through engineering societies, or to labor unions.[37] Engineering society membership has fallen in recent years. One reason is that companies are reluctant to support involvement of engineers in professional societies, either financially, or by allowing time off, or by encouraging membership.[38] Union membership has probably never been strong overall among engineers, except perhaps in certain industries and/or geographic locations, and may be even less so today due to difficulties being encountered by unions in the current economy and overall political climate.

The disciplinary nature of engineering has long been an obstacle to the creation of a central focus for the profession that enables it to speak with one voice. Employers of engineers span a broad spectrum, including large companies, small companies, self-employment, and employment in the public sector, both defense and civilian. Relatively open access has made it possible for those of lower socioeconomic status to enter the profession, although that may be less so today. In addition, engineering has been a major beneficiary of a significant stream of immigrants, many who have come specifically to study engineering here, especially at the graduate level.

Bachelor's degrees awarded in engineering in the United States in 2004 have recovered from a significant falloff in recent years, reaching a level of about 73,000. Degrees awarded in engineering at the bachelor's, master's, and doctoral levels have all increased from 1999 to 2004, partly due to strong growth in computer science. The increases have been continuous, with the exception of doctoral degrees, which dipped in 2002 and 2003.[39] However, some clouds have appeared on the horizon, as will be discussed in the next section. Efforts are being made to reform and revise engineering curricula, viewed by some as being excessively demanding and irrelevant to societal concerns and engineering practice, to be more attractive to and beneficial for students. Among the approaches being taken are to get engineering content into the earlier years, and to emphasize teamwork and real world projects.

C. Engineering Enrollments and Degrees

This can be a fairly complicated topic to get one's arms around. I have relied primarily on two sources: Michael Gibbons, director of data research for the American Society for Engineering Education, and Richard Heckel, founder of the organization "Engineering Trends."

1. The Year in Numbers: 2004–2005.

Here are some excerpts from *The Year in Numbers* by Michael Gibbons, director of Data Research of ASEE.[40]

"Engineering degrees increased at all levels during the 2004–05 academic year. This trend has continued at the bachelor's and master's levels since 1999. Doctoral degrees increased for the third consecutive year. This recent spurt has helped the United States recover from a decade of non-growth that began in the early 1990s. Bachelor's degrees awarded in engineering are back to the levels seen during the late 1980s. This holds true even when accounting for the greater number of computer science degree recipients from engineering colleges in recent years. At the bachelor's level, 73,602 students received engineering degrees, about 700 more than last year. The computer science portion of that total dropped by 8 percent to 8,419. Similarly, master's degrees increased by just over 800 from 2003-04 to 40,650 in 2004-05. The Ph.D. level saw the largest growth, where doctoral degrees grew to 7,333, an increase of 27 percent since 2002.

Enrollment data indicates that this trend has probably peaked. Bachelor's and master's enrollments are both down for the second consecutive year. Growth in doctoral enrollment has slowed considerably. Undergraduate enrollment sustained its high point of 375,000 for the two consecutive academic years beginning in fall 2003 and fall 2004. While enrollment has fallen by 2 percent to 366,361 for fall 2005, the number of freshmen hit a five-year low of 95,750. The fact that freshman enrollment declined indicates that this trend might continue for the near term.

Enrollment trends at the graduate level have diverged in recent years. Since reaching a high of 91,665 students in fall 2003, master's enrollment has fallen steadily to 83,293 in fall 2005. That's a decrease of over 10 percent. Doctoral enrollment grew by just over 1,000 from last year to 57,077. Overall, enrollment at this level has increased by 50 percent since 1999. This massive growth will continue to fuel an increase in doctoral degrees awarded through the end of this decade. Conversely, master's degrees are headed in the opposite direction. The enrollment data clearly show that master's degrees awarded should begin declining in 2006. This trend will continue for the next several years….

The percentage of foreign nationals receiving bachelor's degrees has remained steady at just under 8 percent. The fraction of master's degrees awarded to foreign nationals has retreated slightly from a high of 46 percent in 2002–03 to 42.6 percent in 2004–05. However, at the doctoral level, this portion has increased to almost 60 percent. Consequently, the number of U.S. students receiving doctorates in engineering is virtually the same as it was in the early 1970s…

Degree totals rose at all levels over the past six years. The fastest-growing disciplines were aerospace and biomedical, which increased their undergraduate totals by 102 percent and 137 percent, respectively. Biomedical showed the strongest graduate-level growth, notching totals of 135 percent for master's degrees and 78 percent for doctoral degrees. The largest disciplines of electrical, computer and mechanical engineering generally mirrored the overall trends and

> increased proportionally. Not all areas followed suit. Although civil and environmental engineering fared well at the doctorate level, these disciplines showed only meager growth for master's degrees and declined 10 percent for undergraduates. Chemical engineering bachelor's degrees continued to slide, falling 27 percent from 1999 to 2005. This differed greatly from the 10 percent growth in master's degrees and 36 percent growth in doctoral degrees."

Gibbons summary analysis highlights a number of other factors and developments. Enrollment of women at the bachelor's degree level declined but is doing fairly well at the graduate levels. Nevertheless, the enrollment of women is much lower than their share in the general population. The percentage of African Americans and Hispanic Americans enrolled at all degree levels remain low and haven't changed to any great extent over the past decade.

One paragraph quoted above that needs emphasis is the heavy dependence of the U.S. graduate academic engineering enterprise and, to some extent, the U.S. engineering profession as a whole, on foreign nationals, especially Asians. Gibbons' report contains detailed tables and figures for 2004-2005 as well as some comparisons for longer periods. At the master's level, since 2000, the percentage of master's degrees awarded to foreign nationals has remained above 40%.[41] At the doctoral level, that percentage rose from about 50% to just under 60%.[42] By contrast, the annual number of doctoral degrees awarded to U.S. nationals has remained essentially unchanged since the 1970s.

Two other points can be made here about Gibbons' work. First, as he points out, there clearly is a time lag between changes in engineering enrollments and subsequent numbers of degrees awarded. Second, there are three primary sets of data on engineering enrollments that I am aware of: (1) ASEE, as reflected in Gibbons' quote above; (2) the Engineering Workforce Commission (EWC); and (3) the National Science Foundation. All three sources have somewhat different numbers, in part because of how they the handle computer science. Richard Heckel of Engineering Trends has performed extensive analyses of these data for many years. Recent graphical representation by Heckel of degrees awarded from 1945–2005 indicate pretty good agreement between ASEE and EWC results.[43] However, NSF numbers tend to be lower than the others.[44] Handling of computer science is a complication that accounts for some but not all of the differences.[45]

Gibbons' observed that bachelor's degrees awarded in engineering are back to the levels observed during the late 1980s. Heckel's graphical representation indicates a similar result. However, the previous peak seems to have occurred around 1983–1984 at about 79,000 engineering bachelors degrees awarded.[46] Thus, the ASEE data has not yet shown a recovery that has reached the earlier peak, which followed a rapid rise, starting in 1975-1976 from about one-half of the peak level. Also, since 2000, ASEE numbers are somewhat lower than EWC numbers due to computer science degree differences. However, what is most interesting is the U-shaped trough in bachelor's degrees awarded in engineering that took place over the past 20 years, coupled with the recent fall-off in bachelor's degree enrollment which presages a forthcoming decrease in degrees awarded in a small number of years.

2. Richard Heckel. "Engineering Trends"

Richard Heckel is professor emeritus of engineering at Michigan Technological University and is founder and technical director of the 6-year-old Engineering Trends, an organization that tracks and analyzes engineering degrees, enrollments and research expenditures. In a telephone conversation on August 12, 2006, Heckel said that he thought that offshoring was already having an effect on engineering enrollments.[47] Following a maximum in the fall of 2001, computer degree enrollments plummeted. Not only did freshman enrollments drop, but total full-time undergraduate enrollments dropped as well. Apparently, enrolled undergraduate students at all levels were "getting out." Engineering followed the computer enrollment trend shortly thereafter. Engineering began to lose favor with bright high-school students in 2000 at about the same time as demand for engineers on the part of companies dropped precipitously, as tracked by the College Employment Research Institute of Michigan State University in a detailed survey of companies.[48]

What happened? According to Heckel, high-school students possibly interested in engineering are influenced by the demand for engineers. When engineers are in demand, it draws them to engineering. When demand lags, they do not enroll in engineering. They learn this ("are tuned in") as high school sophomores and juniors. When things do not look good for engineering, they leave and go into more qualitative fields. This was happening during the 2000–2002 time period when outsourcing or offshoring was beginning to become visible, starting with call centers in India. Since then, the perception of engineering as a somewhat perilous career path hasn't turned around. The media are still writing about offshoring. Universities are hiring to replace retirees while student enrollments are dropping. Total full-time engineering enrollments have recently dropped for a year or two now.

We discussed whether the cause of what happened between 2000 and 2002 was offshoring or the dot-com bubble bursting and the economy slowing or both. I mentioned that the economy seems to have turned around but still there were various concerns. The conversation turned back to offshoring when Heckel mentioned an article he had been contacted about prior to publication that appeared in *Bloomberg* (September 20, 2005), in which the headline was "GM Tames Gas Guzzling with $11, 486-a-Year Engineers in India."[49] The article gives several quotes and examples of skills and advantages that specific U.S. corporations derive from offshoring engineering work to Indian engineers. He believes that the article would be very discouraging reading for U.S. high school students considering engineering as a career.

Richard Heckel believes that it is a new world we are living in. The whole structure of the engineering education system will change. We are beginning to see a decline in engineering master's degree enrollments due to the loss of foreign nationals. He believes that engineering doctoral enrollments peaked in fall 2005 and will drop abruptly. Doctoral degrees should begin to decline in about three or four years. Foreign doctoral student enrollments in our engineering schools will dry up. The number of doctoral degrees in engineering awarded to U.S. citizens is now the same as it was four decades ago. Furthermore, the United States trails several Asian countries in the awarding of both bachelor's and doctoral degrees in engineering per capita.[50,51]

3. International Rebound?

One recent sign of a possible increase in students from other countries coming to study in the United States is contained in data released on August 9, 2006, by the Council of Graduate Schools. Based upon this data, an article optimistically headlined "International Rebound: The graduate student population in the years ahead is likely to increase in size—and to have many more Asian engineers"[52] appeared on the same day in *Inside Higher Education News*. According to the article: "(W)hile enrollment for the next academic year won't be clear for a few months, the total number of foreign applications for graduate school in the United States was up 12 percent for the year, and the number of offers of admission was also up 12 percent. Last year, applications were down by 3 percent and admissions were up by 3 percent, as graduate schools struggled to deal with increased competition from other countries' universities and from the impact of tighter visa rules for those wishing to study in the United States." Although the news article does not give comparable figures for the changes from 2004 to 2005 for engineering, the percentage increase for foreign students applying for graduate study in engineering was 19% for 2005 to 2006 while the admission offers made rose by 26%, the most dramatic increase for all fields of study.

The "full report" released on August 9, 2006, by the Council on Graduate Schools does not give the breakdown for engineering by country of origin. However, my recollection is that for many years, engineering has been heavily represented in the fields of study of the incoming foreign student population. If we assume for the moment that the distribution across incoming countries for engineering is the same as for all incoming graduate students, that distribution is as follows for percentage changes in admission offers from 2005 to 2006: China 20%; India 28%; Korea 4%; Middle East -2%. One other interesting statistic: for China, India, and Korea, the percentage increase in admission offers is about the same as for applications; however, for the Middle East, the change in applications was +10% compared with a -2% acceptance rate. This is the first time in three years that admission offers have gone up to students from China and decreased to students from the Middle East.[53]

Debra W. Stewart, president of the graduate school council, said the figures are good news for graduate schools and their universities. "There's no question that we are seeing a real turnaround," she said. At the same time, however, she noted that even if there are similar increases in actual enrollments this fall of new graduate students, total foreign enrollments are unlikely to reach 2003 levels. With many universities in other countries going after top graduate students, Stewart said it was crucial for American institutions to regain enrollment levels now. Long term, she said it was likely that the United States would lose some market share for foreign students, but that if its institutions make up for lost ground now, they can stay competitive for the best foreign students. While Stewart said that some of the progress is due to improvements in the visa system, she noted that the survey found that many graduate schools have taken new steps to recruit foreign students in recent years—in terms of organization, marketing, and funding."[54]

D. Career Trajectories in Engineering. Engineers as Commodities

Two observers of the engineering profession have provided insight into certain recent developments.[55] In a paper published in 2003 and provocatively titled "Are Current Engineering Graduates Being Treated as Commodities by Employers?", Jones and Oberst summarize the situation as follows[56]:

"The employment scene for professionals of all sorts becomes more volatile with each decade. In engineering, graduates of past generations could reasonably look forward to a linear career trajectory characterized by upward mobility and advancement. A typical career back then might allow the graduate to move from strict technical work to creative design work, then on to technical management, and perhaps to general management—often within one firm. In contrast, today's engineering graduate is being told that a typical work pattern will probably involve six or eight or more major job changes during the working lifetime. What is not being said is that such job changes will often be lateral moves, not career progressions. The hiring of engineering graduates by non-traditional employers, seeking their problem-solving and analytical skills for resale to consulting clients, exacerbates the problem."

Not only are moves between jobs likely to be frequent and lateral, they result in periods of unemployment, generally not mentioned, between engagements. The implied "contract" between employees and employers has broken down, both for engineers employed in traditional technical fields as well as those working for broad consulting firms and other non-traditional employers. "Taken together, engineering appears less and less attractive as a career path for many qualified students."[57] Jones and Oberst place their argument in context of decreases in U.S. engineering school enrollments from a high point in the 1980s to the end of the century, the difficult nature of the engineering curriculum, and less attractive job and career opportunities in technical fields.

They conclude as follows[58]: "It is clear to the authors of this paper that employed engineers in the USA have no immunity among all the professions from treatment as a commodity in the job marketplace, even in our technology-driven society. The situation is serious enough that the engineering profession must address it, by positive measures such as awards for meritorious employment practices, or by negative measures, by setting up overt mechanisms to steer engineers away from companies that treat their employees in a non-professional way—hopefully getting their attention and helping them to change their ways on the basis of enlightened self-interest. The major engineering societies in the USA are the only voices that can effectively take on this task on behalf of the profession, and they should do it with deliberate speed."

E. Deconstruction of Engineering Work. Movement Offshore.

In parallel with the idea of engineers as commodities, there is the deconstruction of engineering work. Tasks are more and more being broken down in discrete pieces that require highly specific skills, some of which can be done offshore. Jobs, sometimes ephemeral in nature, are defined very narrowly requiring highly specialized skills, training and certifications.

There is no patience shown by employers with having to retrain people. Through the Internet and on-line advertising, it is possible to attract engineering candidates for these positions from both here and abroad while others who may not meet precise background requirements are left out.

Note that there does not appear to be unanimity concerning the deconstruction of engineering work. In an April 2006 article in *Electronic News*, Ed Sperling writes that “More engineers are being called upon to do more jobs, with 81 percent now supporting designs all the way through the manufacturing and design process.” He quotes one respondent as saying that he has had to deal with an expansion of the scope of the design engineering process. “Besides the basic engineering functions, I have had to become knowledgeable in all phases—from initial concepts to manufacturing.” One cause of this situation is that some engineers are being required to work harder and assume greater responsibilities.[59]

The Sperling article also highlights another trend that concerns some engineers, namely, the growing use of contractors. For example, in the product development cycle, 67% of respondents say that contract manufacturers are either always or occasionally used. “Perhaps even more disturbing, 31 percent of respondents say that contract manufacturers now have the ability to design out products.”[60]

The shift in the location of engineering work has been highlighted in an article entitled “Keeping US Leadership In Engineering” in the April/May 2006 issue of *Chief Executive* by Pradeep Kholsa, Dean of Engineering at Carnegie Mellon University. Khosla’s paper is summarized in an ASEE Digest review as follows[61]: “A decade ago, close to 40% of total engineering work hours were based in the US; by 2010, it is estimated that only 10% of those work hours will be in the US.” (Khosla) reviews the current situation of elements of this change, such as outsourcing, innovation, competitiveness, and globalization. He states that “the US must concentrate on keeping the higher skilled engineering work stateside, thereby ramping up the US worker skill levels and continuing to attract the best and brightest from around the world.”

F. Job Satisfaction.

1. NSF SESTAT Data.

Some information has been collected by NSF utilizing national surveys about job satisfaction for engineers and scientists, both employed and unemployed, that resides within their SESTAT system. I have eyeballed the results of the question on overall job satisfaction collected from engineers in 1997 and 2003. At first glance, I don’t see a whole lot of difference between the two years, either for the total engineering population or for electrical engineering, a discipline that may have been more severely impacted than others by the economic downturn, by offshoring, or by other factors during the 1997 to 2003 period. I haven’t performed any statistical analyses of the SESTAT data.[62]

2. Some On-line Survey Information.

I have come across several articles based on survey results focusing on various segments of the engineering field that indicate that although official unemployment figures are down over the last year or so, there is an underlying dissatisfaction on the part of some engineers with their situation. More job insecurity is perhaps the main element of this dissatisfaction. Some examples follow.

EE—Evaluation Engineering has been surveying professionals in the electronics industry annually since at least 1995. Their annual survey issue provides a good snapshot of changes over the past decade. In an article about the results of the 2005 survey, the author, Judy Bokorney, finds that the industry is stabilizing after some difficult years; however job security remains an uncertainty.

"According to the 2005 *EE-Evaluation Engineering* survey, median salary rose 2.7% to $75,000 this year compared to last year's total of $73,000. Yet optimism must remain guarded as median salary also was $75,000 in both 2002 and 2003 after banner years in 2000 and 2001 where income increased by 8.3% and 4.6%, respectively."[63]

"Job security is still tentative among (718) *EE* readers who responded to the survey. A total of 61% indicated they do not feel more secure in their job this year than last year. Most survey takers said that, overall, they feel secure in their present job (52%) with 34% feeling very secure and 14% not secure. ……Many of the respondents interviewed connected job security with job satisfaction. Most survey takers were satisfied in their job (53%), 29% very satisfied, and 18% not satisfied." Compared to a year ago, satisfaction levels were about the same. The respondents ranked their three most important work-related issues as follows: salary (66%), work/life balance (63%) and job security (54%). Outsourcing was not one of the top three; the percent responding was not given.[64]

A 2006 *EE-Evaluation Engineering* survey article has the upbeat title "Engineers Optimistic About Industry Comeback," reflecting some improvements in several aspects of importance to survey respondents. Median salary was up to $80,000, up 6.6% compared to last year. "85% were either satisfied with their current job and 76% with their overall career. Most (of the 650) participants have been at their existing job for six to 14 years. This year, 19% …. said they were more satisfied, and most felt the same level of satisfaction (57%). A percentage (24%) was less satisfied…. A total of 78% of those who took the survey have worked 15 years or more in the electronics industry. In fact, most participants or 73% said they would recommend a career in the field of engineering to their children. … A total of 85% of respondents said they felt secure or very secure in their current job. But on the contrary, 65% said they feel less secure than last year."[65] With the evident upturn in the electronics industry, this last result seems somewhat surprising.

In addition to the *EE-Evaluation Engineering* surveys, there are other articles available online from the 2004 to 2006 time period that report the results of surveys of engineers working in a variety of fields or specialties. They include surveys of design engineers with electrical engineering and computer backgrounds, information technology professionals, mechanical and design engineers, and engineers in chemical processing[66]. There is neither time nor space here to deal with these individually. My quick assessment of these articles is that for those surveyed, which usually means employed engineers, things have improved since around 2000. In 2006, they are probably the best they have been in this fledgling century. This is due in no small part to salaries beginning to show increases. However, there remains considerable concern about job security, and job dissatisfaction is significant.[67] Sources of job insecurity include concern about offshoring of jobs and changes in the nature of engineering work. More recent, somewhat less optimistic information about salaries is contained in the next section.

G. Salaries

The latest report of the STEM Workforce Data Project released in August of 2006 examines trends in salaries of STEM workers from 1995 to 2005, using data from Current Population Surveys.[68] According to the press release accompanying issuance of the report:[69]

"Median annual salaries for all workers increased from $32,000 in 1995 to $34,000 in 2005 (in constant 2005 dollars), while the medians for all STEM workers increased from $53,000 to $56,500 over the same time period….. Among the STEM occupations, median salaries were highest for engineers and for mathematical and computer scientists. Both of these broad occupational groups also saw increases in their inflation-adjusted base pay between 1995 and 2005—from $61,500 to $63,500 for engineers and from $54,500 to $59,000 for mathematical and computer scientists. Median salaries for all professional workers combined dropped slightly from $48,000 in 1995 to $47,000 in 2005. Within this group, median salaries for physicians and surgeons increased from $76,000 in 1995 to a peak of $89,000 in 2004, before dropping to $80,500 in 2005.

"While some of the short-term salary shifts presented in the data may seem alarming, they may simply be the result of sampling errors or the result of changes in the Standard Occupational Classification (SOC) adopted in 2003. Or, these shifts may be a harbinger of things to come. Data for 2006 and beyond will be needed to adequately assess the longer-term trends.

"'The salary trends presented in this report reinforce a general sense that prowess in science and technology is not an especially respected element of current U.S. culture,' says Richard Ellis, the report's author. 'In some business circles, technical proficiency seems to have become regarded as a commodity that can be easily acquired whenever necessary from just-in-time contractors.' Ellis has handled technical compensation research projects for the Engineering Workforce Commission, IEEE, and the American Chemical Society for more than twenty years."

The report itself has additional information for engineers and engineering disciplines. In constant 2005 dollars, median annual salaries grew modestly for all engineers from $61,500 in 1995 to $63,500 in 2005. However, engineering salaries peaked in 2001 at $65,500 and have not been that high since. The main engineering disciplines display somewhat similar behavior. Salaries vary from discipline to discipline. In 2005, aerospace engineers led at $71,000 while civil engineers trailed at $59,000. "Recently, aerospace, computer, and electrical and electronics engineers have reported higher median salaries than other engineering specialties. At the same time, salaries of chemical engineers, who have been among the more highly paid engineers in the past, are now headed down. Within mathematical and computer sciences, computer software engineers report notably higher earnings than other occupations in the broad math and computer science group, while computer support specialists report much lower levels of pay."[70] The comparability of data from 1995 to 2005 for computer hardware engineers and for electrical and electronics engineers suffers from changes in occupational coding in 2003. During the decade, engineers were the highest paid of STEM workers with math and computer scientists in second place.[71]

Although salaries for engineers exceeded those for all occupations ($34,000 in 2005), they lagged behind those for lawyers and for physicians and surgeons. Lawyer's salaries grew, though not steadily, from $75,000 in 1995 from $83,500 in 2005. Similarly, for physicians and surgeons, the growth was from $76,000 in 1995 to $80,500 in 2005. In contrast to the very modest gains in real purchasing power for engineers during the decade, which essentially flattened around 2001 and declined slightly thereafter, management and executive occupations did better "and began to exceed those in the professions. Growth in the pay for chief executives has not slowed down at all."[72]

One other grouping of interest to the engineering profession is that of engineering technicians. The median annual salary in constant dollars in 2005 was $41,000 only $1,000 more than in 1995. It peaked at $43,000 in 2004. Managerial categories in STEM occupations were first created in 2003. The salary for engineering managers peaked at $97,000 in 2004 and fell to $93,000 in 2005. Computer and information systems mangers fell from $77,500 in 2004 to $74,500 in 2005. Interestingly enough, the median annual salary for engineering managers exceeded that for chief executives by $7,500 in 2004 and fell behind by $3,000 in 2005.[73]

I believe that it is very important to work recent data into these kinds of analyses. This report is the first that I have come across that utilizes 2004 and 2005 data in an analytical way for salaries. Let me close this section with additional quotes from the report itself relevant to what the numbers might mean for issues such as offshoring.

"These data measure typical market values for salaries obtained by people in different occupational groups. Notice the recent trend of leveling off or small drops in the gains in purchasing power obtained earlier in the decade. One wonders if data for 2006 and 2007 will revert back to the favorable compensation trends experienced during the dot-com / telecommunications bubbles, or instead continue to signal possible stagnating or declining real values of pay for at least some people in STEM professions. Certainly there are signs that prowess in science and technology is not an especially respected element of current U.S. culture. In some business circles, technical proficiency seems to have become regarded as a commodity that can be easily acquired whenever necessary from just-in-time contractors.

Levels of concern have been rising about current business trends and other pressures that could constrain scientific and technical salaries, such as possible consequences of outsourcing, offshoring, and the employment of foreign workers in the USA. Despite all this, overall levels of employment in STEM professions have held up in recent years. Some observers of the scene say that the numbers may be propped up by guest workers and may obscure serious problems of underemployment among experienced natives."[74]

H. Unemployment

An important source of insight and information into the situation faced by unemployed electrical engineers is the biennial IEEE-USA Unemployment Survey. The results of statistical analysis of the 2004 Survey by Laura Langbein of American University are available.[75] I will not describe them in any detail here. Langbein summarizes the survey results, and highlights the efforts of IEEE members to seek reemployment as well as the greater difficulty that older engineers have in becoming reemployed. There has been a shift over the past three or four biennial surveys in the type of former employer IEEE members worked for, with a higher percentage of the unemployed coming more recently from non-government positions. In addition, employers are providing much less service for laid-off workers than they did before. "...(E)mployers provided severance in only 54% of the cases (compared with 90% in 2002) and extended benefits in only 27% of the cases (compared with 48% in 2002)."[76] The outlook in 2004 was more pessimistic than in 2002. "In 2002, 30% reported that they would not recommend engineering to their sons and daughters. In 2004, this increased to 41%."[77] The 2006 survey results will probably not be available until late in 2006.

As was pointed out earlier, the unemployment rate for electrical engineers reached a record high of 6.3% in 2003. Although it fell to 2.1% by the first quarter of 2005, total employment declined from 363,000 in 2003 to 335,000 in March of 2005. One possible explanation for the decline is that a significant number of electrical engineers may be leaving the profession.[78]

I have not come across any other surveys of unemployed engineers in the limited searching I have done. Such surveys do not seem to be as plentiful as those of employed engineers. National data bases such as SESTAT and those at the Bureau of Labor Statistics undoubtedly contain some relevant information that requires digging out. These surveys might be more useful for our purposes if they would incorporate some questions about offshoring as a possible cause of unemployment.

I. Status of Engineering. Careers in Engineering

A survey posted by *USA Today* on May 23, 2005, provides results from a Harris Poll of 1,012 adults conducted Aug. 10–15, 2004, of the prestige in which various occupations are held by the public. Almost all professions have experienced an erosion in prestige during the past 30 years. (The one exception is that of 'teacher'—up from 29% in 1977 to 48% in 2004.) The percentage of those assigning great prestige to engineers fell from 34% to 29% since 1977. That 29% number sits right below Members of Congress (31%) and right above Athletes (21%). The highest categories are Scientist and Doctor, both at 52%. Some other occupations of note are Lawyer (17%) and, bringing up the rear, Real Estate Broker/Agent (5%). "According to an increasing body of evidence, how much prestige the outside world assigns to a job plays a sizable role in job satisfaction. That could portend consequences, not only for the well-being of worker and the success of companies, but also for the health of the economy."[79]

And then there is that old spectre—perception. There is and has been plenty of concern out there in recent years that people, including parents and grandparents who give career advice to their children and grandkids, are wary of engineering as a career path. Perception can be as important as reality, or even more so when it comes to career choice. I have not attempted to collect and analyze the information that is out there, some from surveys, some anecdotal. For some statements to this effect, see Section IIIB.

In 2004, the American Society for Engineering Education (ASEE) published a guide to attract prospective engineering students listing the top ten benefits of an engineering career.[80]: Number one on the list of rewards and opportunities that an engineering career offers is Job Satisfaction. Number 6 is Financial Security. Number 7 is Prestige. Number 8 is Professional Environment. Number 10 is Creative Thinking. These five strike me as being on somewhat shaky ground these days. The other five—Variety of Career Opportunities, Challenging Work, Intellectual Development, Potential to Benefit Society, and Technological and Scientific Discovery—may arguably be somewhat less problematic. ASEE's monthly magazine *PRISM* has been highlighting various engineering programs that focus on and involve engineering students in serving society.

J. Wanted: Tech Talent. Stay Rates for Foreign Doctoral Students

1. Wanted: Tech Talent

Every year, *U.S. News and World Report* publishes a guide which ranks graduate school programs within major fields of study. Universities take these rankings very seriously and go to great lengths to come out high in the rankings. My impression is that the rankings are used fairly widely by students making choices not only about which universities to attend but also about which graduate fields to pursue.

In the 2007 guide, which appeared on the newsstands in 2006, the section on engineering not only ranks graduate engineering programs by major discipline but also contains an essay by Alex Kingsbury entitled "Wanted: Tech Talent."[81] Although one tends to be somewhat skeptical of the recruiting tone of the article, it does seem to indicate that things are looking up for engineering graduate programs and the demand for engineers. Among the points made are that engineering university student output is not meeting demand, that older engineering workers are retiring and that engineers are needed not only in manufacturing but also in service industries and in jobs that are not "strictly engineering." According to Kingsbury, "(a)fter several lean years, engineering graduates are receiving multiple job offers, lucrative signing bonuses, and relocation allowances. Recruiters are flocking back to campuses, particularly in search of students holding advanced degrees." He quotes the head of engineering career services at Cornell as saying "I don't see that look of anxiety in students' eyes this year, which means they're finding jobs…" According to the article, the tone is up, the numbers are up, and the salaries are up—a rosy picture.

Kingsbury also discusses the job outlook by engineering discipline/field. Five of these fields are stated to be "booming," namely, civil, environmental, biomedical, and mechanical engineering and nanotechnology, with employment growth for some ranging from 17 to 27% by 2014. However, the fields of electrical engineering and computer science & engineering are conspicuous by their absence.

2. Stay Rates for Doctoral Students on Temporary Visas

Because of the importance of foreign graduate students to the engineering enterprise in the United States, it is valuable to know whether or not they are entering the U.S. workforce or returning to their home countries after graduation. In November 2005, Michael Finn, who has performed careful analyses related to this question for many years, authored a paper entitled "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2003."[82] For the category "computer/EE engineering" (N=688), the following percentages of students who received their doctorates in 1998 while in the U.S. on temporary visas were still in the United States: Year 1999, 78%; Year 2000, 76%; Year 2001, 75%; Year 2002, 74%; Year 2003, 70%. For the category "other engineering"(N=1,894), the equivalent results show a similar decline from a 69% stay rate in 1999 to a 64% stay rate in 2003.[83] Suffice it to say that more students here on temporary visas receiving doctorates in engineering have stayed in the United States in recent years than have returned home. The percentages could even be higher for students from China and India. Whether this situation will persist remains to be seen. According to Finn, "(i)t appears clear that the increase in stay rates that has gone on for over a decade has ended."[84]

K. Concluding Remarks

In Section II, information has been provided that establishes some context for the consideration of offshoring of U.S. engineering jobs that will follow in Section III. Several pages have been devoted to the engineering workforce, including information from the Engineering Workforce Project and the STEM Workforce Data Project. Both recent and historical tends in engineering employment, unemployment and salaries, where available, have been presented. Another substantial portion of Section II is devoted to information on enrollments in engineering degree programs and degrees awarded as harbingers of possible changes in the workforce.

There are additional survey data out there which, if analyzed, might shed further light on workforce issues. These include the national sample survey population data collected for scientists and engineers by the National Science Foundation in their SESTAT system and by the Bureau of Labor Statistics. More detailed comparisons can be made, for example, for engineers, for certain variables for the years 1997 and 2003, including the results of a question about job satisfaction. IEEE-USA has an on-line data base of salary and unemployment data going back a number of years that can be manipulated and analyzed. However, it is not clear that these additional analyses will further illuminate the offshoring situation for two reasons. First, these surveys do not collect information directly related to offshoring and its effects on the workforce. Second, offshoring is a fairly recent phenomenon. Keeping track of what is going in would be facilitated by timely information on the workforce. However, there is a time lag of a year or two or more before data for the most recent year becomes available for analysis.

Understanding the engineering profession is clearly relevant to the issue of the impact of offshoring. Engineering underwent phenomenal growth after World War II. The contributions of engineers to the economy, the standard of living, and the national defense have been extraordinary. Yet as the 21st century gets underway, the U.S. engineering profession finds itself facing major challenges. Among these are a somewhat fractured profession that has difficulty speaking with a unified, strong voice, a predominantly salaried workforce that may be less convinced that jobs are secure and well rewarded than in the past, and a graduate engineering education enterprise that is heavily dependent on foreign students, coupled with continued difficulty in attracting U.S. citizens. Perhaps initiatives proposed by the National Academies and pending legislation in the Congress will result in additional resources to increase financial support for attracting U.S. citizens to pursue degrees and careers in engineering.

In my opinion, the biggest challenge of all is provided by the impact of globalization and the offshoring of U.S. engineering jobs on the engineering workforce and the profession. The way engineering is being performed and where it being performed is changing at an accelerating pace. In Section III, offshoring of engineering jobs will be examined in more detail.

I had hoped when I started on this paper that a good deal of the contextual material I have assembled and discussed above would be readily available in one or a small number of places. Unfortunately, I did not find this to be the case. <u>It is essential that someone—some organization (preferably more than one)—somewhere look at the matters outlined in Section II concerning the engineering workforce and profession on a detailed, continuous, timely basis and make their results widely available</u>. Although there are some pockets of useful information, to my knowledge, much potentially valuable surveying, data gathering, and analysis focused specifically on the engineering workforce and profession are not being performed.

III. THE IMPACT OF OFFSHORING ON THE ENGINEERING WORKFORCE AND PROFESSION

In this section, I have synthesized a variety of information that bears on the impact of the offshoring of engineering on the U.S. engineering workforce and profession. I begin presenting the views of Samuel Florman, an NAE Workshop steering committee member and by focusing on the views of those in the engineering profession most directly affected, namely engineers themselves. Although relevant quantitative data on offshoring are hard to come by, I include what I have come across, imperfect though it may be. Also included in this section are the views of knowledgeable individuals who either have interesting things to stay or who have conducted studies or both. I have tried to stay focused on engineering and to include information that spans a range of engineering fields and disciplines. However, topics likely to involve not only engineers but scientists as well are covered, such as the impact of production shifts to China and elsewhere on jobs and the offshoring of innovation to Asian countries. In addition to information gleaned from U.S. sources, material has been included that describes a significant push towards the development of the engineering services outsourcing market in India. I will also have a few things to say about the broader economic and political context in which conflicting views about offshoring find themselves.

The topic I have undertaken to write about in a short period of time has many dimensions and there is much information out there to sift through. I have tried not to deal with the issue of the state of government statistical data relevant to offshoring and/or trade in services. That appears to be well covered it at least three major reports that have come out within the past year.[85] And, although I have included material relevant to the impact of offshoring on various engineering disciplines, I have excluded the detailed consideration of specific industrial sectors of the kind that are being covered by the authors of the sector-specific papers being prepared for the NAE Workshop. An exception to this is a description of work by Ernst on the offshoring of chip design.[86]

A. Prologue. Some Views From Samuel Florman

The impact of offshoring on the engineering workforce and profession varies considerably, depending on who you talk to, what their vantage point is, and what aspects of the offshoring phenomenon you choose to focus on. I learned that almost three years ago when I prepared and presented a background paper on Global Outsourcing of Engineering Jobs[87] to the Program Committee of the National Academy of Engineering. I was convinced when I went into the meeting that the topic was extremely important for the future of engineering education and the engineering profession. I assumed that my persuasive and enthusiastic presentation would win the day. Instead, for the most part, there was silence, broken with a few polite questions. What I vividly remember from that meeting was one person's view that, in effect, offshoring was an inevitable consequence of globalization and not something that the NAE would want to be concerned about.

A lot has happened in the past three years. For one thing, offshoring is much more visible, both to the public and in the political arena. The public learned that calls for technical assistance to deal with everyday problems were being answered in far away places. And significant numbers of engineers and computer scientists found their livelihoods threatened as jobs moved offshore. Their statements have not gone unheard by some of their political representatives, their professional organizations, or their unions. Researchers and commentators, mostly from outside of engineering but some within the profession have begun to take the matter seriously and provide useful research and/or insights. One of these persons is Samuel Florman.

Sam Florman is a distinguished engineer who is co-chairman of Kreisler Borg Florman Construction Company and a member of the National Academy of Engineering. In addition to his many accomplishments and awards for his engineering work, he has made unique contributions to the profession in the form of more than 200 articles dealing with the relationship of technology to the general culture. He is the author of six books, including *The Civilized Engineer*, *Blaming Technology*, and *The Existential Pleasures of Engineering*. In 1982, he was honored by the American Society for Mechanical Engineers for his effective contributions to a better understanding and appreciation of the engineer's worth to contemporary society.[88] He clearly is someone who has been able not only to view engineering from the inside but to step back and observe it holistically.

Mr. Florman has always been immensely proud of the engineering profession as well as someone who senses when things may need fixing. His growing interest and concern about offshoring of engineering jobs and its impact on the profession are chronicled in a May 2004 article in *Technology Review*.[89] In 2002, two articles appeared in the *Wall Street Journal* that caught his attention. Both were written by science writer Sharon Begley. The titles were "As We Lose Engineers, Who Will Take Us Into the Future?,"[90] and "Angry Engineers Blame Shortage on Low Pay, Layoffs and Age Bias."[91] And then, Florman writes, "…suddenly, while I wasn't looking, disaster had struck. In the first quarter of 2003, the unemployment rate for electrical engineers had soared to seven percent, a full point higher than the national average, which was itself causing alarm. And while this figure has moderated somewhat, to 5.3 percent in the first quarter of this year (2004), the crisis has become increasingly disturbing. This is so because its origins seem to be more profound and immutable than anything we have experienced before. <u>The pressures of globalization and free trade have spread rapidly beyond the manufacturing sector to imperil the careers of even the most talented engineers"</u> (emphasis added).[92]

Florman goes on to outline the situation faced by the engineering profession as follows: "Two new phenomena have become particularly threatening: the outsourcing abroad of ever more complex intellectual work, and the importing of tens of thousands of technical workers through the granting of special visas. And lest we think that this is just a momentary crisis affecting IT people in the swiftly moving world of high tech, an article in *Structural Engineer* entitiled "Visas and Outsourcing" complains that the problem is beginning to harm civil engineers. …. Clearly, historical forces are in motion that are difficult for us to comprehend and impossible for individuals to control. <u>An engineering degree is no longer a ticket to steady, risk-free employment</u>"[93] (emphasis added).

Florman sketches how various interest groups, the engineering professional societies, engineering educators, and the National Science Board are reacting to or attempting to deal with contextual issues that relate to the situation he has described. And he sees hope in the background that an engineering education provides young people, enabling them to pursue not only careers in engineering but also a wide variety of careers outside of the profession. He suggests that young people pursue engineering careers less for economic security and more for doing something that they really enjoy doing. However, he feels the situation is such that more than individual action is called for. Political involvement by the traditionally apolitical engineering profession is needed, through the efforts of professional engineering organizations and, if need be, unions.[94] He hopes that "the current difficulties concerning outsourcing and visas will be mitigated through a combination of god sense, good will, and wholesome political contention."[95]

In an article published in summer 2005 in *The Bent*, the magazine of Tau Beta Pi, the engineering honorary society, Florman focuses on the outsourcing issue and takes issue with a view expressed by Wm. A. Wulf, president of the National Academy of Engineering (see Section IG3). He begins by characterizing the relationship between the engineering profession and the nation and society as having been "strong and beneficial", something he has felt comfortable about, even complacent. However, his current concern is reflected in the title of the article "My

Profession and My Nation: A Worrisome Confrontation."[96] I will not attempt to summarize the article here . However, its last two paragraphs, quoted below, serve to sharpen the debate.

> "Where do I stand? My instinct—contrary to the well-considered and well-intentioned opinion of President Wulf—is to support the engineering societies which seek, by legitimate political means, to protect their members from foreign competition. What is excessive? Well, John Kenneth Galbraith said that politics "consists of choosing between the disastrous and the unpalatable," and in this instance I believe it would be disastrous to so disenchant a large number of American engineers that the profession's image would be damaged and its appeal to talented youngsters diminished. Thus, might the hard-headed pragmatists reduce our nation's technological well-being, the very cause they seek to support.
>
> And, while I'm quoting economists, let me use the words of John Maynard Keynes to respond to Dr. Wulf's comments about protectionism perhaps being OK in the short run but not in the long. It is widely known that Keynes said, "In the long run we are all dead." Less familiar is his preceding sentence in the same essay: "Long run is a misleading guide to current affairs."[97]

B. Offshoring: Some Views of Affected Engineers

Sam Florman's article in *Technology Review*, a widely read magazine that is sent gratis to all MIT alumni, elicited a range of responses. I quote some excerpts below that reflect the frustration and disillusion that some readers found with the situation in engineering on May of 2004.

Posted 5/23/42004 by Rumments. "My son is thinking of going into engineering. I will see if I can interest him in something else like Banking or an MBA, or maybe a lawyer. He likes the idea of engineering and like his dad has the inborn skills. But there is no place for him to work here. As too many people go for too little jobs the salaries will not be enough to have a decent life. With visas allowing engineers in the salaries will not climb…. I would love to re-educate to give myself a better chance but certifications within my field are in the 5K range for each domain, and no one gives scholarships to 40 year old men to go back to school…. It's a shame. Leave engineering to people in growth countries. Advise your children to seek the kind of jobs that can't be shipped out and can be done here. Yes engineers will exist here, but when there are too many for too few jobs, it's not a pleasant career."[98]

Posted 5/20/2004 by Too Embarrassed. "I am a software engineer who started on mainframes in the early 80s, and have continued on till now. At times I did earn a good amount of money, however I also had to constantly spend a lot of cash to maintain my skill set in a career in which things change very fast. Companies never really pay for education, they would rather fire and rehire for the programming flavor of the day. So here I am …, being out of work since August, no more savings left, can't travel and visit my son, and can neither pay for my re-education or my son's primary education. I became a software engineer because its hard and challenging work that at one time garnered respect and good pay, and I loved it. Now there just isn't any work…. Offshoring will cause more problems that it will fix. As China and India open more and more, the cost of American products will not decline fast enough for this economy to enjoy the growth it had …. I guess I will go from a person who paid taxes who can't pay them now, to a person that requires state assistance. 22 years of experience, great references, and I can't find a job that I can pay my basic bills at a salary less than ¼ of what I was making. Perhaps it's hopeless, so I say don't become an engineer……"[99]

Posted 5/19/2004 by anonymous. "……(T)he large electronic company I work for is slowly shutting down one plant in Tennessee to export the jobs and products overseas to Singapore and the PRC. Approximately 50 engineers are being RIF'd over a six month period. Only about five have found jobs within the organization but this requires relocation to another city or overseas. The rest have been looking all over the country and only ten have been successful in finding employment so far. I myself have been RIF'd at least five times in my career. Fortunately, I've always been able to jump to another company pretty quickly……. I've inquired with most of the engineers in our group what should be done about this action that profoundly affects my engineering community. Out of about 40 people, I only found two that felt that the government should take action about the loss of engineering jobs…… The rest feel that the actions would only delay the inevitable because globalization is inescapable and are resigned to this. The irony is that the Chinese and Indian workers I work with will also be RIF'd (about seven in all). As a result of their H1B visa requirements, however, they will have to return to their respective countries within 15 days if they don't find a job with somebody who will sponsor them. So the negative effects of globalization are felt even among the notorious H1B "job-stealers."

I expect that like agriculture in the 20th century, the engineering employment pie (with respect to nonmilitary, nongovernmental opportunities) as well as manufacturing in the United States will continue to shrink with respect to this country's economy in the 21st century……. I do not believe that engineers will rise up and fight this battle in a unified voice. Groupthink and political debate with respect to the engineering field is something they find repugnant."

Business Week response, May 29, 2006. An article in the May 1, 2006, issue of *Business Week* entitled "A Red Flag in the Brain Game"[100] resulted in a number of reader responses. Here is one by Ron Johnson:[101]

Having worked for a well-known semiconductor company for over four years, I have watched as my job was eliminated, the next job "offshored," and I have trained a foreign engineer to do my most recent job so it, too, can be offshored. This same company recently acknowledged it has been paying its engineers and technicians well below market, upwards of 15% to 20%. The present CEO, at an employee open forum three years ago, stated that for every $1 spent on engineering in the U.S, the equivalent in India is 20 cents. Do we really have a shortage or are executives trying to flood the labor market to make these skills even more of a commodity?

If there is indeed a shortage of engineers in the U.S., as claimed in your article and many analysts, the laws of economics—including globalization—are to blame. Why rack up thousands of dollars in student loan debt to obtain an engineering degree only to have continually diminishing prospects upon graduation?"

Telephone conversation. June 18, 2006. In June 2006, I had a conversation about offshoring and the job situation with an executive of a small networking firm. An electrical engineer by training, he had joined the firm in 2004 after a brief interval between jobs.

He estimates that thousands of engineers in the telecommunications industry in the New England technology corridor lost their jobs due to outsourcing around the time he joined his current firm. Roughly half to two-thirds of these engineers are reemployed as engineers, maybe half in the same industry and half in other industries. Very few, if any, of these are being paid more than before they were laid off. Some took cuts to avoid layoffs. He thinks they are now making 20–30% less than in 1999–2000. Of the hundreds who were laid off, roughly half to two-thirds retired or took jobs in non-engineering fields (e.g., teaching, construction work, retail sales).

He bases his estimates on either personal knowledge of individuals or from reading various online job search websites or networking job groups (Yahoo, other) during the period of peak layoffs around 2000 to 2004. If the job search group information from previous years is still available online, it could be a good source of data to help answer questions concerning the extent of offshoring due to job loss.

C. "The Human Face of Offshoring"

Ron and Anil Hira, in their book *Outsourcing America*, devote a chapter to the effects of outsourcing on individual workers and communities.[102] They argue that offshore outsourcing or offshoring will produce two immediate effects on U.S. workers—their jobs will be displaced and the makeup of the engineering workforce will change. They are skeptical of some economists' claims that new, comparable, or better jobs will be quickly found for displaced workers and that retraining programs will prove effective. And changes that shift engineers at an early stage into project management and away from technical jobs are problematic. Another immediate impact is the downward pressure on wages resulting from having to compete with engineering talent that is being compensated at a much lower salary level. Not only salaries are affected but also health benefits, pensions and job security. Furthermore: "(W)ithout stable, high-wage employment, consumers will no longer be able to spend or borrow, thus returning the favor to those companies that are now consciously undermining our standard of living."[103]

Hira and Hira begin their section on the impact on individuals with the following. "No one can put numbers on the amount of personal suffering and anxiety that offshore outsourcing causes U.S. workers, either through job loss or the threat of job loss. As one worker put it succinctly, "I am not a statistic." Or as Jeraldean Evans, a fifty-eight-year old veteran programmer from Oakland, California, says about having to train her foreign replacement: "My value as a human being was taken away from me."[104] Even those who have not been displaced are terrified. One worker described offshore outsourcing as a threatening monster and told us that many engineers in Minnesota are "frightened of this thing (outsourcing) which seems to have only one outcome: All engineering jobs will go overseas or salaries will take a significant dip.""[105]

The Hiras describe three of many cases in which engineers have had to contend with training their own replacements prior to having been laid off. Situations arise in which employees are pressured to do so or are assured that their jobs were not in jeopardy prior to their being laid off. In one example, computer programmers, after being told they were going to be laid off, were required to train their replacements or lose their severance packages. Their replacements were foreign workers in the United States on L-1 visas making one-third of the salaries being earned by the Americans being laid off. They also describe the very real difficulties that displaced workers face, included low paying jobs, bankruptcies, and in at least one case, suicide. And these stories are referred to as being just the tip of the iceberg.[106]

Three individuals in engineering and IT are highlighted who were impacted negatively by offshoring and are trying to do something about it. One, Natasha Humphries, is involved in a group, Techunites, that aims to unionize workers in information technology. A second, Scott Kirwin, started the Information Technology Professional Association of America (ITPAA) to help improve conditions for IT workers who were being mistreated by their companies. John Pardon has abandoned the IT field and has joined the group Rescue American Jobs as an activist and policy analyst.[107]

In discussing the impact of offshoring on communities, the Hiras point to the precedent of communities in the 1980s that were hurt by manufacturing job losses in the "Rust Belt." Although white-collar services jobs may not be as concentrated geographically, there are communities which may be vulnerable, as companies with major employment impacts move call-center and other jobs overseas. They go on to point out that offshoring can affect communities in many ways, including loss of a significant middle-class tax and revenue base, resulting in a decline in local services and public infrastructure. The examples of Clinton, Virginia, and Reading and Allentown, Pennsylvania, are given. A table is provided of states with large numbers of high-tech jobs which might possibly be affected. Two examples of major areas with significant concentrations in the IT field where the impacts have already been felt are Silicon Valley in California and Austin, Texas.[108]

Hira and Hira devote a section to the special case of the Indian-American community in the United States. The section is informative and nuanced; I recommend that you read it. Among other things, they point out: "Many Indian-American entrepreneurs are also benefiting greatly from the offshore outsourcing trend, leveraging their ties to the United States and Indian business communities. Some are high-profile, like Vinod Dham, the "father of the Pentium," who has started the offshore venture-capital firm NewPath Ventures; Sunil Wadwhani, CEO of Pittsburgh-based IT offshoring powerhouse iGate; and Atul Vashistha, who runs the offshoring advisory consulting firm NeoIT. There are countless smaller start-up companies …. And even more Indian Americans who are acting as the global supply coordinators for Fortune 500 firms." Also highlighted is the fact that "many Indians who came to the United States to study or work are returning to India, some even after staying on the United States for many years."[109] As of 2004, some 35,000 Indians were estimated to have returned to Bangalore, where many feel that the quality of life is better for them there than in the United States.[110] My guess is that this reverse brain drain phenomenon may be accelerating and that offshoring is a significant contributing factor.

Ron and Anil Hira conclude with a section that summarizes their concerns about "real and potentially devastating impacts of offshore outsourcing on Americans—on the personal, community and national levels." They view offshoring as contributing to a decline in the standard of living of many Americans and they fear that it does not bode well for the future of "hard-working, well-educated, and highly skilled American workers." And they speculate that "perhaps the most devastating impact is felt by the next generation, who will enter the job market with few clear prospects for gainful employment. What motivation can our next generation of the best and brightest find, if the most high-paying and technically skilled jobs are following the wave of manufacturing jobs lost earlier? These impacts will reverberate on the national level, with equally important long-term consequences unless corrective actions are taken. We as a nation will begin to lose our capabilities in national security, in the ready supply of technical and engineering talent, and in the ability to maintain our economic competitiveness."[111]

D. More Feedback from the Affected Workforce. "Offshore-Tracker."

Techsunite is a project of the Communications Workers of America, AFL-CIO. Their informative web site has a feature called "Offshore Tracker" which keeps a running tab on jobs offshored and jobs lost. This tracking is done by soliciting information from Techsunite members and viewers of their website about companies that have taken offshoring or job layoff actions. Offshore Tracker asks for information about the background and characteristics of workers and jobs that were affected. There does not appear to be a way to determine tallies solely for engineers as opposed to non-engineering personnel. And the data clearly is not anywhere near to being from some sort of national statistical sample. Nevertheless, the results are of interest and the methodology has some merit as an indicator of what is going on and what is of concern to workers in the IT and communications labor movement. And I know of no other efforts underway to try to track and quantify jobs offshored and jobs lost as a result in this manner.

From January 1, 2000, through July 25, 2006, Offshore Tracker lists 469,996 jobs offshored and 204,587 jobs lost, presumably as a result of offshoring. Of these, 95% of jobs offshored and 89% of jobs lost were reported for calendar years 2003, 2004, and 2005, with the highest figures for 2003. As of July 25, 2006, no offshoring or layoffs have been reported during 2006. One can speculate why. Perhaps offshoring and layoffs are no longer occurring, although frequent recent news articles about such activity by industry would seem to preclude this explanation. Or perhaps Offshore Tracker isn't tracking these days, which would be my guess since the totals have not changed from July 25 through September 18, 2006. Or perhaps offshoring has become so common and laid off workers so resigned to it that they are not submitting responses to Offshore Tracker anymore. The web site also lists numbers of jobs offshored or lost by individual companies during recent company actions. The top three "culprits" were EDS, IBM and Dell. The most recent entries are from mid-2005.[112]

E. The Changing Nature of Corporate Global Restructuring: The Impact of Production Shifts on Jobs in the U.S., China, and Around the Globe

Bronfenbrenner and Luce, in a paper prepared at the request of the U.S.-China Economic Security and Review Commission (USCC), have developed a methodology to track and analyze the extent of production shifts out of the U.S. to China and other countries. Their work combines online media tracking with corporate research information and yielded a data base that includes information on all production shifts from the United States to China announced or confirmed in the media for two time periods, October 2000 through April 2001 and January 1 through March 31, 2004, referred to below as the earlier and later time periods.[113]

Among the major highlights of the study are the following. Production shifts have increased considerably out of the United States from 2001 to 2004, mainly to Mexico, China, India, and other Asian countries. In the later (2004) period, there were 58 shifts to China from the United States, the primary source of such movements into China. Production shifts out of the United States in the earlier period were simple site-to-site shifts to a single country. In the later period, of 255 shifts out of the United States, 48% were simultaneous shifts to "near-shore" countries like Mexico and China. Production shifts to China in the later period represent a broad cross-section of industrial sectors compared with a narrower range in the earlier period. Among the additions are aerospace, industrial equipment and machinery, metal fabrication, and production, plastics, glass, and rubber.[114]

Bronfenbrenner and Luce also track job shifts. Based on their tracking results for the first quarter of 2004, and assuming that media tracking captures two-thirds of production shifts to Mexico and about a third of the shifts to other countries, "these data suggest that in 2004 as many as 406,000 jobs will be shifted from the US to other countries compared to 204,000 jobs in 2001." Furthermore, the authors indicate that the data suggest that the Bureau of Labor Statistics (BLS) grossly underestimates the total number of jobs lost out of the United States due to production shifts. (For first quarter 2004, BLS reports 4,633 private sector workers in companies with 50 or more workers lost their jobs in this way compared with an "absolute minimum" of 25,000 in their study).[115]

In the United States, because of various obstacles, including disallowance of non-manufacturing jobs in IT, workers who lost jobs due to production shifts in first quarter 2004 filed claims for Trade Adjustment Assistance in only 31% of cases. At the same time, unionized workplaces are being disproportionately affected negatively by the shifts in production. Some 72% of companies shifting jobs from the United States to China were owned by U.S. multinationals. "The companies shifting jobs from the US to China tend to be large, publicly held, highly profitable and well-established." Some regional breakdowns within the United States are provided, as are breakdowns of industrial sector activity changes between the earlier and later period, as well as comparisons with European countries.[116]

The authors end their executive summary: "We conclude that our data speak to a growing phenomenon of global corporate restructuring and capital mobility. Throughout the world, US and foreign owned multinationals are simultaneously shifting production from high-wage countries to multiple low-wage destinations, both near shore and off shore, with China as one of the primary destinations for all countries. <u>Yet three years after our original report to the USCC, there continues to be no government mandated reporting system to track production shifts out of the US</u> (emphasis added). Absent government-mandated reporting, the continued funding of research such as this becomes essential to efforts to track the changing trends and effects of global capital mobility on US workers and the US economy."[117]

1. Afterthoughts.

This study by Bronfenbrenner and Luce illustrates the valuable information that tracking of online announcements and confirmations of production and job shifts can provide to illuminate offshoring. I believe that there may be one or two others who are utilizing this approach. I don't know if any are attempting to break out information that specifically tracks engineering jobs offshored. I have not contacted the authors to see if they have done further analysis for more recent time periods. Based on current newspaper accounts, my guess is that even more production and job shifts will have occurred recently. One thing I did not emphasize here is the importance of "near-shoring" to Mexico which is documented in the study.

F. BLS Mass Layoff Statistics Data on Offshoring

For the first three quarters of 2004, the Bureau of Labor Statistics began to collect information in their mass layoff statistics program about the movement of work, in order to learn more about outsourcing and offshoring. The protocol for collection and validation is rather complicated and I won't go into it in any detail. The information is asked of employers. Questions include the following: (1) "Did this layoff include your company moving work from this location(s) to a different geographic location(s) within your company?"; (2) "Did this layoff include your company moving work that was performed in-house by your employees to a different company, through contractual arrangements?" If the answer to either question is "yes," employers are asked "is the location inside or outside the U.S.?" and "How many of the layoffs were as a result of the relocation?"[118]

Sharon Brown has reported on the results of this data collection effort for the first three quarters of 2004.[119] The story told in Brown's paper is not a simple one and I will leave it to the economists and labor statistics experts to sort some of it out. For a "mass layoff" to be counted it has to involve at least 50 people and there are other requirements. Data are collected from employers, not those who were laid off, and have only been collected since 2004. Thus, it is likely to miss a lot of what is of interest here. However, it represents one of the few government efforts I know of to collect data that directly address offshoring. As more experience is gained, improvements to the survey are made and more years become available, to could be a useful indicator.

Here are some excerpts from the Brown paper: "Between January and September 2004, employers took 3,478 mass layoff actions that resulted in the separation of 685,929 workers from their jobs for at least 31 days. … (Of those), (t)he events involving movement of work (either domestically or out of the U.S.) were associated with the separation of 52,309 workers, about 11 percent of all separations resulting from nonseasonal and non-vacation mass layoff events… Employers were able to provide information on the specific separations associated with the movement of work component of the layoff in 279 actions, 84 percent of the total for the first three quarters of 2004… Nearly 41,000 separations were associated with these 279 actions."[120]

The paper describes the distribution of layoffs involving movement of work by industry in some detail. Manufacturing industries were prominent. In addition, some analysis is provided of layoff events, for which data has been collected prior to 2004. For example, it is noted that for the information-technology producing industries, layoff activity had peaked in 2001 or 2002 and was down considerably in 2004.[121]

Of the 279 actions involving movement of work reported above, one out of four were out of the United States and 66% involved the movement of work within the company. Of those offshored, 56% of the relocations were to Mexico and China. When work was moved under contractual arrangements to a different company, the work was offshored in just over four out of ten cases. "The separation of 10,722 workers were associated with out-of-country relocations, slightly more than one-fourth of all separations related to movement of work and about 2.3 percent of all extended layoff separations excluding seasonal and vacations. Domestic relocation of work … affected 27, 326 workers."[122] Thus, about 28% of the separations due to movement of work involved offshore relocation.

G. Globalization and Engineering: The Fall 2005 Issue of the NAE "Bridge"

The fall 2005 issue of the NAE journal *The Bridge* has several articles which deal with offshoring of engineering.[123] In this section, I will summarize three of these.

1. "Offshoring and the Future of Engineering: An Overview."

In the lead article entitled "Offshoring and the Future of Engineering: An Overview,"[124] Martin Kenney and Rafiq Dossani begin by cautioning that "Engineering as a profession in the United States and other developed countries may soon face a crisis……Offshoring …can not only 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.[125]

"Nearly as important as job displacement is the possibility that offshoring could create significant downward pressure on engineering salaries… 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, engineering as an academic discipline is likely to become less attractive to U.S. college students, unless he engineering curriculum changes to address the new reality."[126]

"The McKinsey Global Institute (MGI) (2005)[127] recently examined the potential for offshoring globally from developing nations to 10 industries, three of which—automobiles, software, and information technology (IT) services—are illustrative of the potential for 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."[128] The authors go on to note that the MGI report found that only 2,000 of these automotive jobs had actually been offshored, a lag they attributed to the conservative nature of the industry. However, that may be changing. (See Section 3S.) Kenney and Dossani also point out that General Motors and General Electric are hiring engineers in low-wage nations, using job descriptions in some cases that are similar to those used in the United States.[129]

a. Civil Engineering.

Kenney and Dossani provide insight into what is happening within the civil engineering profession, particularly construction. Because of the nature of what civil engineers do, as well the importance of construction to the U.S. economy, they point out that it might appear that civil engineers would be immune from offshoring. Not so. They cite examples of large and small firms, in the United States and also in Europe, that offshore work. Offshoring occurs not only to India but to other destinations, including Poland, the Philippines, Vietnam, China, and Latin America. They indicate that "At a minimum, offshoring dampens upward pressures on (U.S.) wages. By opening an overseas office or contracting work overseas, firms can limit their high-cost domestic head count."[130]

They conclude their analysis of civil engineering as follows. "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."[131]

b. Evaluation. Conclusions.

The Kenney-Dossani paper contains a great deal of value for understanding engineering offshoring. There is a discussion of the situation in electrical and computer engineering (covered elsewhere in my paper) as well as a section which indicates that start-up companies are going global, spurred in part by encouragement from venture capital companies. A 'highlight' in their paper states that "The relocation of new jobs by small firms could lead to the "relocation of entrepreneurship" per se.[132] And, in their words, "The future can not be guaranteed, and our mental models of the location of jobs crated by the technology entrepreneurship process must be adjusted accordingly."[133]

There is a discussion in the Kenney-Dossani paper of possible responses to the offshoring situation. Although agreeing on the need to improve K–12 education and well as higher education, they do not believe that more funding for education alone will address the problem of increasing offshoring of engineering jobs. They point out the changes occurring in the career trajectories of engineers and the nature of what they do, emphasizing that they will need to be able to coordinate and manage global projects. They suggest that licensing of engineers could be changed to incorporate "a system of regular, midcareer renewals." They believe that American engineering students could benefit from learning more about environments in, for example, India and China through first-hand experience. And they warn against trying to meet the offshoring challenge by simply adding more content to improve the technical skills of these students in their curricula.[134]

Some excerpts for Kenney and Dossani's conclusions are the following: "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."

"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[135] (emphasis added).

2. "Impact and Trends of Offshoring of Engineering Tasks and Jobs"

Ron Hira's paper in the fall 2005 *Bridge* focuses on the impacts of offshoring on employment, on observable trends in offshoring, and on policy responses.[136] An electrical engineer who went on to get a doctorate in public policy, Hira has been studying and writing about offshoring for several years. A professor at Rochester Institute of Technology, he is the co-author of the book *Outsourcing America*[137] and currently serves as vice president for career activities for IEEE-USA. Hira begins his paper as follows:

"Many companies are transferring tasks and jobs that have traditionally been done by American engineers to lower cost countries where engineers earn as little as 10 percent of the salaries Americans earn. Company managers, making rational decisions, hope to save up to 70 percent in net costs by offshoring work. Although no government organization has reliable figures on exactly how many engineering tasks have been moved to low-cost countries in recent years, observable trends indicate that offshoring is accelerating in scale and scope. No doubt these changes have important implications for American engineers and the U.S. national innovation system; but engineers have little objective information to help them adapt to these changes, and, in spite of widespread media attention, policy makers have so far chosen to do nothing in response to these structural changes to our innovation system."[138]

In considering the impact of offshoring on employment, Hira indicates that three impacts are expected: "job displacement for U.S. workers; a change in the mix of U.S. occupations; and downward pressure on wages for jobs that are newly tradable across borders."[139]

a. Displaced Workers Survey.

For those U.S. workers who lose their jobs as work is shifted offshore, Hira states that: "In reality, the adjustment process—workers seeking and finding opportunities at other companies, in other geographic regions, and/or in other occupations—is difficult. The data on reemployment outcomes are limited, but we can get an indication from the Bureau of Labor Statistics Displaced Workers Survey (2004).[140] The survey shows that, of workers who were displaced between 2001 and 2003, 35 percent were still unemployed in January 2004, and of the

65 percent who were employed, only 43 percent earned as much as they did before displacement. Thus the empirical data show that displaced workers are not reemployed rapidly (one in three remains unemployed) or at the same or higher wages (three in five took pay cuts)." Hira goes on to state that these results are largely consistent with results of similar surveys conducted since 1979, in which "(s)ignificant numbers of displaced workers are likely to stay unemployed for extended periods of time, and many who do find work take substantial pay cuts."[141]

b. Sluggish job creation, unemployment in EE, CS.

At the time Hira's paper was written, the economy was recovering from recession. However, he notes that the level of job creation has not tracked with the economic expansion. "Although most macroeconomic indicators, such as robust expansion of gross domestic product (GDP) have been favorable, job creation has been far weaker than during any other recent recovery from recession." More recently, he has indicated that "the IT job market has improved in the past two years, but I wouldn't say we have robust growth."[142]

Hira shows a figure based on BLS data adapted by IEEE-USA that plots the unemployment rate for electrical engineers, computer scientists, and all workers for the years 1972 to 2004.[143] One striking feature of this graph is the convergence of the EE and CS unemployment rates with those for all workers for the years 2001 through 2004. Until that time, unemployment rates for electrical engineers and computer scientists were considerably below those for all workers. Hira observes that EE and CS levels of unemployment were higher during the years 2001 through 2004 than for any other four-year period since 1972. "In 2003, for the first time, the unemployment rate for electrical engineers (6.2 percent) exceeded the national unemployment rate (6 percent). To put this in historical perspective, throughout the whole decade of the 1980s, unemployment among electrical and electronic engineers never rose above 2 percent, despite national unemployment rates that peaked at 9.7%."[144]

"For the first time in the 31 years that IEEE-USA has been surveying its members, median compensation declined in 2003. Although unemployment rates improved markedly in 2004, this was partly due to increased hiring and partly due to engineers dropping out of the profession and looking for work in other occupations." Hira points out that many factors, including the telecommunications bust, have contributed to the sluggish market for EEs. Members of this profession have expressed greater concern about offshoring in this regard than those in some other professions. He also notes that engineers unemployed for extended periods of time may harbor an additional burden in that they risk losing cutting edge skills in a profession in which skills become obsolete relatively rapidly. [145]

c. Job skills, visas and offshoring.

Hira, in his leading role over the past several years with IEEE career activities, indicates that at every IEEE meeting he attends, he is invariably asked, "What new jobs should I be training for? What new skill sets will I need?" He has found it difficult to answer that question because of several factors, including the reluctance of companies to reveal their plans for offshoring as well as the lack of government data. It also raises difficulties for engineering educators who are seeking to modify their curricula to make their students more employable. He also discusses observable trends in offshoring, especially the growing movement towards offshoring higher-level tasks, and the movement of more labor overseas by companies with traditional business models. He comments on the profit margins of Indian vs. U.S.-based offshoring firms.[146]

Hira has been concerned with the role of visa programs in facilitating offshoring. His analysis goes like this: "…(M)any offshore outsourcing firms, based in India and the United States, are using the U.S. government-administered H-1B specialty occupation and L-1 intracompany transfer temporary visa program to gain competitive advantages. The vast majority of the employees of these companies in the United States are H-1B or L-1 visa holders. Very few American citizens or permanent residents are hired and, in general, H-1B visa holders are not sponsored for permanent residence. … This serves two purposes. First, it enables companies to pay their on-site workers lower wages than comparable U.S. workers. Second, it facilitates the transfer of work overseas by providing a training ground for key employees….. In many cases, workers are part of a formal process known as "knowledge transfer," whereby U.S. workers are asked to train their foreign replacements. In some cases, this is a condition for the U.S. worker to receive severance pay and unemployment insurance. The foreign workers then return to the offshore location where they effectively act as liaisons to customers; in addition, they train additional offshore workers."[147]

<u>d. Policy responses. Conclusions.</u>

Hira outlines six general areas for providing policy changes to deal with the economic and employment challenges offered by offshoring.[148]

"1. Collecting better intelligence to improve labor market signals and clarify the impacts of offshoring in technological innovation and national security.

2. Ensuring that government policies, such as tax incentives and visa programs, do not accelerate offshoring.

3. Taking preventative measures to help workers adapt before they are displaced.

4. Providing palliative measures to help workers adapt before they are displaced.

5. Providing recuperative measures to help workers obtain better employment.

6. Adopting measures to expand technological frontiers and accelerate the creation of high-wage jobs. (The focus should be on solutions that are geographically 'sticky' and that help workers rather than companies)."

Policies for offshoring is a topic that I have not considered in sufficient detail in my paper. It is an exceeding important topic that needs attention.

Hira concludes by pointing out that many companies are responding to the competitiveness challenge by pitting foreign workers against U.S. workers and it is the U.S. workers who are being left out. He is skeptical of government policies that emphasize increased spending on R&D leading to new breakthroughs as a solution to offshoring because given the current mindset, the bulk of the design, development and production jobs may very well wind up overseas. Greatly increasing the number of U.S. engineering graduates probably won't be effective either, unless there are substantive changes in engineering education to provide different skill sets than their foreign engineering counterparts. "We need different, not more scientists and engineers. Achieving this will be much more difficult than most people realize, but it is time we began to talk about the best ways to respond to offshoring."[149]

3. "A Disturbing Mosaic."

In the final paper in the NAE *Bridge* fall 2005 issue on Globalization and Engineering, NAE President Bill Wulf describes what he views as a 'disturbing mosaic' in which "(t)he United States is trading the long-term health of U.S. research and education for the appearance of short-term security."[150] What President Wulf finds disturbing falls into two clusters. The first cluster consists of reactions to the September 11 attacks on the World Trade Center which have included: (1) new visa policies which have served to restrict or delay the flow of students and visitors to the United States; (2) possible export control changes which would in essence keep foreign graduate students from participating in research; and (3) the growth of use of a government classification category for "sensitive but unclassified" (SBU) information which is being used in some cases to suppress criticism or to attempt to restrict publication of legitimate research results.[151]

Wulf's second disturbing cluster deals with disinvestment in the future. He singles out four items as being of concern: (1) the demise of corporate research and development; (2) the decline or flattening of funding for research in the physical sciences and engineering over several decades, coupled with the more risk-averse approach to research funding by government agencies; (3) the shift to treating education as a private good, making college more difficult for many students, including those who aspire to engineering careers, and especially for those who are economically disadvantaged; and (4) the loss of human capital, as reflected by the disturbing pattern of low engineering enrollments in the U.S. relative to other nations.[152]

Wulf, who begins his paper with a discussion of Tom Friedman's book, *The World is Flat*, comes back to the flat world and offshoring of U.S. engineering and scientific jobs in his closing remarks. Although he states that these occupations are the backbone of U.S. innovative capacity, he does not believe offshoring to be a piece of his disturbing mosaic. What he does find disturbing is a protectionist reaction to it. Wulf then states: "Of course we must help those who lose their jobs, by providing financial assistance and retraining, and it may even be appropriate to protect some jobs as a short-term tactic. But in the end, the country will be strengthened only by learning to compete in this new, flat world. Among other things, this means that we engineers must deliver value that justifies our cost, but the U.S. engineering community has yet to figure out how to do that."[153]

H. Engineering Degree and Outsourcing Studies At Duke University

At Duke University in the Engineering Management Program, recent activity involving both graduate students and faculty has been receiving attention. In a report, *Framing the Outsourcing Debate*,[154] that has been widely circulated and discussed, the research team examined the problems associated with previous efforts to compare the numbers of engineering graduates in the United States with those in India and China. They concluded that, contrary to those who paint a dim picture of the relative numbers of U.S. engineering graduates being produced, "(a) comparison of like data suggests that the U.S. produces a highly significant number of engineers, computer scientists, and information technology specialists, and remains competitive in global markets."[155]

One of the faculty leaders of the Duke effort, Vivek Wadwha, an Executive in Residence and Adjunct Professor, has been active in spreading this message. He writes occasional columns for *Business Week* magazine[156] and has testified before a Congressional committee hearing.[157] In his testimony, Wadwha concludes: "The numbers that are at the center of the debate on U.S. engineering competitiveness are not accurate. The U.S. may need to graduate more of certain types of engineers, but we have not determined what we need. By simply reacting to the numbers, we may actually reduce our competitiveness. Let's better understand the problem before we debate the remedy."[158]

This summer, Wadwha and students are conducting a survey of employers (and universities?) to understand trends in engineering offshoring. According to the survey introduction: "We hope to better understand what types of jobs are currently being out outsourced, what the future holds, and to make recommendations on how engineering education can be improved to give our students and the U.S. a long-term competitive advantage."[159] The survey is quite detailed, with three major sections, one on Personal Background Information, one on Engineering Education and Hiring Practices, and a third on Engineering Offshoring.[160] As of June 21, 2006, the Duke student-faculty team had received responses from about 25 companies and was hoping to obtain at least 25 more through the summer. Getting responses from companies has evidently not proven to be easy.[161] It is hoped that the report will be available in time for the October NAE Workshop.

Prior to the current Duke outsourcing survey, the work described above provides useful information on an important aspect of the context for offshoring but does not get to the heart of the matter. The great engineering graduates "numbers debate" is a tricky business which has aroused a lot of interest and which I will not comment on in this paper in any detail. However there are several points that struck me in reading the Duke report. First, Wadhwa et al. have done a good job in pointing out the difficulties in comparing numbers of engineering graduates among countries when what constitutes an "engineer" can vary greatly. Second, it gets even worse for non-IT and non-electrical engineering fields because the information available on the number of engineers in these fields is evidently meager, especially for India. Third, Wadwha concludes that by comparing apples to apples and oranges to oranges rather than comparing apples to oranges, the United States fares better in its supply of engineers than the recent National Academies' Augustine Report indicates.[162] There are at least two reasons I can think of for being skeptical of this conclusion. First, the Duke study uses data on engineering, CS and IT degrees to imply that "per every one million citizens, the United States is producing roughly 750 technology specialists, compared with 500 in China and 200 in India."[163] This is taken as an indication that U. S. numbers are adequate. But what constitutes adequacy? Should countries in the same stage of development with different internal and external needs and requirements have roughly equal numbers of engineers per capita? Second, the Duke study does not look at trends or projections into the future. At least one projection I am aware of indicates the United States falling behind somewhat in the production of PhD scientists and engineers from foreign universities by the year 2010 compared with China and especially European Union countries.[164]

J. Which Engineers Are More Offshorable?

It would be great if we could develop operational categories for classifying which engineering jobs are most likely to be offshored and which are most likely to remain in the United States. For example, it seems somewhat obvious that engineering jobs that operate and maintain civil infrastructure can not be easily offshored, although foreign nationals and/or foreign companies can be brought in to perform such work. The recent flare up about Dubai running U.S. ports comes to mind. On the other hand, purely technical, analytical, computer-based design work is a much more likely candidate for offshoring. Three approaches for classifying jobs by their vulnerability to offshoring will now be presented.

1. Tradable vs. Non-tradable Services.

One classification grows out of economics and is based upon the division between tradable and non-tradable services. According to a recent study by Jensen and Kletzer: "Contrary to conventional views of service activities as non-tradable, we find a significant number of service industries and occupations that appear tradable and substantial employment in these tradable activities."[165] If you substitute "offshorable" for tradable, the relevance of this information is readily apparent.

2. Transactional vs. Dynamic Engineers.

The Duke University team (See Section IIIH) has put forward a way of classifying engineers utilizing two categories, dynamic engineers and transactional engineers. "Dynamic engineers are individuals capable of abstract thinking and high-level problem solving using scientific knowledge. These engineers thrive in teams, work well across international borders, have strong interpersonal skills, and are capable of translating technical engineering jargon into common diction. Dynamic engineers lead innovation. The majority of dynamic engineers have a minimum of a four-year engineering degree from nationally accredited or highly regarded institutions."[166]

"Transactional engineers may possess engineering fundamentals, but not the experience to apply this knowledge to larger problems. These individuals are typically responsible for rote and repetitive tasks in the workforce. Transactional engineers often receive associate, technician or diploma awards rather than a bachelor's degree.… Due to time and budgetary restrains, sub-baccalaureate programs are rarely capable of placing strong emphasis on research, group work, applied engineering, or interdisciplinary thinking."[167]

The Duke study qualifies these descriptions by adding that the statements about degree requirements for their two categories are not a hard and fast rule. They point out that a number of science and technology leaders have had little traditional education and that a bachelor's degree from a good university doesn't guarantee that the recipient will be "dynamic." Without this qualification, all those receiving bachelor's degrees in engineering would seem to qualify as being dynamic engineers. In my opinion, the categories are two idealized extremes that may be of rather limited utility.

The bottom line of the Duke study with regard to the classification business seems to be that: "Dynamic engineering jobs are difficult to outsource; individuals with these skill sets are virtually always in demand."[168] In contrast, it is the services that can be provided by transactional engineers that are or could be outsourced. Maybe so, but my guess is that there are plenty of engineers who got caught up in the bad times of the 2003–2005 time period who would either fall into the dynamic category or argue that they are dynamic and suffered anyway.

3. High-tech vs. low-tech skills, jobs and wages.

Still another distinction is one that is made between high-tech and low-tech jobs and workers. In a May 2006 article by Jeremy Leonard prepared for American Sentinel University,[169] the author looks at Bureau of Labor Statistics data on employment growth in various categories of the information technology industry. According to Leonard:[170] "Not withstanding the rapid development of information-technology industries in India and other countries with lower labor costs, the risks of the United States losing high-end IT jobs are much smaller than recent high-profile reports suggest. A closer look at employment trends during and after the 2000–2001 recession shows that, with few exceptions, most of the job losses that stoked offshoring fears were cyclical in nature and have been recouped. IT offshoring risks are limited to low-end occupations (such as programmers, coders and support specialists) that are labor intensive, easy to codify, or require little face-to-face contact. "High-end" jobs—that is, those which require advanced degrees in computer science or information systems as well as a good understanding of management and business processes—show no signs of secular decline, and are in fact now growing at rates common in the 1990s boom."

The Leonard article comes up in a number of industry and trade association websites. I have come across only two articles on the web that view it critically. One by Russell Shaw does not seem to take issue with the analysis, only the author's motives.[171] The second finds Leonard's analysis "fair and decisive, but it suffers from two conceptual flaws."[172] The first is that the splitting of jobs into low-end and high-end is arbitrary. The second is believing that high-end IT jobs and low-end jobs exist independently from each other.

Ron Hira is skeptical about the results being put forward in the Leonard study[173]. "The story being told in the report is that only low-end IT jobs are vulnerable. We know the assertion that there is a simple division of labor—where the US retains high-end jobs and offshores the low-end work—is not supported empirically. For example, IBM just announced a $6 billion investment in India with great fanfare.[174] IBM is moving and consolidating key software processes (something called Service Oriented Architecture) in Bangalore. This is high-end work. IBM will have ~18% (55k) of its worldwide workforce in India by the end of this year, up from ~2% (6k) just three years ago. The presentations by the IBM executives emphasized that this is high-end work in their presentations and believe that the talent pool in India is still very deep. There are plenty of other examples of high-end IT work moving offshore including R&D by Microsoft & Google. … American Sentinel University is an on-line school that specializes in computer science and IT degrees. They have an obvious interest in promoting a positive view on the future of computing professions in the US to prospective students."

Catherine Mann of the Institute for International Economics has used the categories of low-wage and high-wage workers to look at technology related occupations for IT from 1999 through the end of 2004. In a PowerPoint slide headed "New Engineering Occupations: IT a Microcosm for All Engineers." Mann reveals that the total number of "Call Center and Low Wage Technology Workers" declined by 31.7% over this period. The average annual wage for this group in 2004 was $26,539. In contrast, "Total High-Wage Technology Workers: Applications, Networking, Analysts, Database" increased by 17.3%. The average 2004 annual salary for this group was $71,680. A subset in the high-wage group, computer programmers do not do well, falling by 25.1% whereas, mid-level occupation computer support specialists gain in number by 6.2%. Mann indicates that the low-wage jobs are in real trouble from trade and technology whereas there has been an increase in the total number of jobs available at middle and high levels that demand integrative and analytical skills. However, in the high-wage category, increased 'codification' is putting programming jobs at risk.[175]

K. Immigration, Visas, and Offshoring

This is a complicated topic which really deserves much more attention than I can give it here. There are several elements to consider:

1. Guest workers, including engineers, enter the United States on H1-B and L-1 visas, subject to certain quotas and regulations. While recognizing the important role that these individuals have played in strengthening the S&T capability of the United States, Hira and Hira have called for reform, pointing out the pitfalls and the effect on offshoring as follows:[176]

> "In an increasing number of cases, the visas are being used to bring in cheap foreign workers who replace Americans. The visas should be used as a last resort, not a first choice for cheap labor. With unemployment rates for IT personnel at record levels, it was unbelievable that industry used up its quota of HI-Bs for 2004 and 2005. The exploitation of lax visa requirements has actually accelerated the process of offshore outsourcing."

A somewhat different point of view is offered by Richard Florida in his book, *The Flight of the Creative Class: The New Global Contribution for Talent*.[177] Florida sees the United States facing a grave threat to its economy and its ability to stay competitive. The threat derives from, among other things, what he describes as the "closing of America." Contributing to this closing are increasing restrictions on immigration and the outcry against offshoring. Whereas Florida's brief treatment of offshoring presents both sides of the issue, he is concerned that the clamor about foreign labor taking U.S. jobs will hinder the ability of the United States to compete for global talent. According to Florida:[178]

> "My own view is that outsourcing is a natural consequence of economic evolution, and that it alone poses a minor threat to American jobs and living standards. It's when outsourcing is taken together with the new global

> competition for talent, coming from countries such as Sweden, Finland, Canada, Australia, New Zealand, and others that America's real competitiveness challenge becomes clear."

Florida's book makes a compelling case for the importance of immigrants to the U.S. scientific and engineering workforce and the economy.[179] Not only are the numbers of foreign-born engineers in the workforce and foreign students studying engineering in the United States vital to our scientific and technological prowess, their individual contributions and accomplishments outweigh their sheer numbers. Citing data from a study by AnnaLee Saxenian,[180] immigrant engineers from China and India were running about 30% of the high-tech companies in Silicon Valley. Companies started by immigrants grew steadily between 1984 and 2000, and were responsible for generating 70,000 jobs and $20 billion in annual revenue.[181]

One last point that Florida makes is relevant to the engineering profession. It is sometimes argued that the United States should welcome highly educated, highly skilled immigrants with open arms while closing its borders to those with less of these qualifications. He points out that making the distinction between low-skilled and high-skilled immigrants is not necessarily easy, particularly over time.[182] There are undoubtedly many personal examples of the highly educated readers of this paper whose parents or grand parents came to this country as low-skilled immigrants. The engineering profession has long provided this kind of upward mobility.

My own bottom line on the complicated interaction between offshoring, immigration, and visas is that we need to continue to maintain openness to immigration while at the same time ensuring that U.S. engineers are given priority and are not put at a disadvantage or ignored.

L. Science and Technology for International Development

I have long had a professional and personal interest in the application of science and technology to improve the standard of living and quality of life of people in less developed countries[183]. From this vantage point, what is happening in global outsourcing strikes me as being one of the bright spots in what over time has been an often-discouraging picture. For example, India, which invested a significant amount of scarce resources in science and technology and in educating scientists and engineers, now finds that it has a growing sector of substantial economic importance, the software industry, as well as others by means of which it can hold on to more of its highly trained professional workforce rather than have them migrate to more- developed countries[184]. In fact, it now appears to be attracting back to its shores Indians with significant skills and accomplishments who have lived and worked for substantial periods of time in the United States.[185]

Offshoring may have the potential, as some hope or advocate, for being a win-win situation for countries at various stages of economic development. However, as Paul Samuelson[186] and as William Baumol and Ralph Gomory[187] have warned, under certain conditions the high-wage country can lose out.

There are many members of the U.S. engineering profession who have strong ties with engineers in developing countries, which are, in some cases, their country of origin. There are others who have been active through international meetings and in projects aimed at improving the standard of living and quality of life for people in those countries.[188] Whereas offshoring of engineering jobs has clearly had detrimental effects upon individual U.S. engineers, there are undoubtedly many of these engineers who view themselves as part of a profession that is international in outreach and perspective and who hope that the benefits of technology will reach out to people everywhere.

M. The NASSCOM-BAH Report: "Globalization of Engineering Services—The Next Frontier for India"

NASSCOM, the National Association of Software and Service Companies, is described on its website as India's "premier trade body and the chamber of commerce of the IT software and services industry in India." Among its initiatives is maintaining "a close interaction with the Government in formulating National IT policies."[189]

On August 4, 2006, NASSCOM released a major report prepared by Booz-Allen and Hamilton (BAH), in conjunction with an Engineering Services Summit in Bangalore, India. The Theme of the Summit was "Off-shoring Engineering Services: The Next Frontier & Potential for India." Conference sponsors including not only well-known Indian companies associated with offshoring but also several Indian engineering services companies, including L&T e-Engineering Solutions, Neilsoft, and Onward Technologies Limited. Here are some excerpts from the web pages of these companies to illustrate the kind of engineering work they perform:

The mission of L&T e-Engineering Solutions is "(t)o provide high quality engineering solutions using cutting edge technology to help customers achieve their objectives of innovation, cost reduction and shorter time-to-market. L&T e-Engineering Solutions, a Strategic Business Unit (SBU) of Larsen & Toubro Limited, is one of India's leading engineering service providers. Backed by engineering pedigree and state-of-the-art infrastructure, L&T e-ES caters to the product lifecycle management needs of various industries including Automobile, Aerospace, Ship Building, Plant Engineering, Construction Equipment, Process Industry, Heavy Engineering and General Machinery."

"Neilsoft provides India-based off-shore engineering services (CAD/CAM/CAE) for global clients in the mechanical engineering segment who want to leverage India's high quality technical resource(s) pool to lower their cost-structure and completion time for product engineering." The company is active in automotive, industrial machinery and equipment, and ship building and marine equipment domains. Services for the mechanical/manufacturing segment include product design and analysis (CAE), CAD services, tool(s) and fixture design, engineering catalogs and CAD customization.

Onward Technologies Ltd. describes itself as "one of the fastest growing engineering design service providers—it is a service partner to the worldwide manufacturing industry, with a range of engineering services." The company is "an ISO 9001:2000 certified firm and with the main assets of multiskilled people, supports global clients in high-end engineering design and analysis." One activity highlighted on the website is the following. "Internet connections and advances in interactive design software, meanwhile, make it increasingly possible to design, test, and reassemble industrial prototypes of highly complex products on computers. Using 3-D computer simulations of a virtual prototype, mechanical engineers and fluid dynamics specialists at Onward Technologies Ltd. in Pune are helping to design virtually every piece of a cylinder tractor engine due out in 2007 from a major farm-equipment company."

1. Engineering Services Summit, Bangalore, India. August 4, 2006.

The Engineering Summit in Bangalore served as a vehicle for highlighting the NASSCOM-BAH report on the engineering services market, which will be discussed in some detail below. According to the website: "(T)he summit provides an opportunity for IT companies in India to understand the trends in the outsourced engineering services market, capabilities of third-party vendors and critical success factors. CIOs of user organizations in the sectors of automotive, hi-tech, industrial automation, defense, and construction will gain insights into innovative strategies being followed by global companies in product design. For industry analysts, government and media, the event will provide an opportunity to understand the scope of the opportunity and country competitiveness." In addition to a plenary session focused on the key highlights of the report, sessions were held "on trends defining the global engineering services market by verticals and case studies," the emergence of China as a competitor in this market, and the action agenda for the industry and NASSCOM to position India strongly within the engineering services domain."

2. The NASSCOM BAH Report.[190]

The report, *Globalization of Engineering Services—The Next Frontier for India*, contains a wealth of information about offshoring of engineering services and bears careful scrutiny. I have only had access to a 13 page executive summary. The full report is quite expensive. Currently, only about 1 to 2% of all worldwide engineering services is estimated to be offshored. However, by 2020, the projection in the report is that the percentage offshored could increase by an order of magnitude to 15 to 20%. This occurs while the total estimated spending on worldwide engineering services is projected to grow to more than a trillion dollars, hence by a third or more. If we ignore for the moment the obvious uncertainties associated with projections, this indicates that the component of engineering services being offshored is projected to grow at a much faster rate that the component that stays at home.

A summary of the report, as it appears on the NASSCOM website, follows[191]. I have included it in its entirety and then focused on other aspects of this report because I think it sheds considerable light on what the U.S. engineering workforce and profession will have to contend with in the years ahead.

a. Summary.

"A new window of opportunity is opening now for India. Even as Indian vendors continue to move from strength to strength as providers of Information Technology Outsourcing (ITO) and Business Process Outsourcing (BPO) services to companies around the world, the possibility now exists for India to add a third major services growth stream—Engineering Services Outsourcing (ESO) —to its rapidly evolving economy.

Engineering services is a huge market: Global spending for engineering services is currently estimated at $750 billion per year, an amount nearly equal to India's entire gross domestic product. By 2020, the worldwide spend on engineering services is expected to increase to more than $1 trillion.

Of the $750 billion spent today, only $10-15 billion is currently being offshored—a tiny fraction of the total. India brings home about 12 percent of today's offshored market, which it currently shares with Canada, China, Mexico, and Eastern Europe. By 2020, we estimate that as much as 25 to 30 percent of a much larger $150 to $225 billion market for offshored engineering services could belong to India—as much as $50 billion in annual revenue—if the country builds the capacities, capabilities, infrastructure, and the international reputation it needs to become the preferred destination for these complex, high-value services.

Some of those elements are in place; others are not. On the positive side, India has the single largest pool of engineering talent among the emerging countries capable of taking on this kind of work—more than Russia and China combined. The current graduate talent pool suitable for ESO and ITO/BPO work in India represents 28 percent of the total in low-cost countries. The outsourcing boom has also created what one might call the habits of success: extensive experience in forging strong client partnerships, in building strong, technically focused organizations, in competing in the fast-changing global market, and most importantly, in creating the business model necessary to deliver value to clients thousands of miles away.

However, India must also overcome some serious challenges if it is to succeed. First, although India trains more engineers suitable for BPO and ESO than any other low-cost countries, not all are equipped with the skill sets required to succeed in this market. Even allowing for a healthy growth rate of 4 percent a year in the number of graduates, the projected number of engineers with the right specialized skills will not be nearly enough to meet the potential demand. Second, India's weak engineering and physical infrastructures are likely to hamper growth as well. As opposed to ITO/BPO, ESO has close links with manufacturing and it may be difficult for India succeed without significantly enhancing manufacturing capabilities—not easily accomplished given the infrastructural constraints. ITO/BPO success has been driven by companies investing in almost “standalone” facilities to de-risk themselves; however, this won't work with manufacturing.

Achieving more than a moderate degree of success in ESO will require a serious commitment from India's business and political leadership to make India a more attractive business destination. To capture its full potential share of this new business, India needs to take steps to address the gaps. While the infrastructure improvements that India must take are nothing out of the ordinary for an emerging market, they will require attention and commitment from all involved parties.

To capitalize on its opportunity, India must equip five to seven cities with world-class infrastructure over the next 14 years (by 2020). It must expand its opportunities for engineering education. And it must market itself in a systematic way, to let corporate decision-makers around the world know that Indian engineers can do much more than code. Without serious investments in education and physical plants, and an unprecedented campaign that joins business and government leaders to meet these demands, ESO could be a missed opportunity for India—and part of another country's boom."

b. The Potential Market.

In a section on the potential market, the report cites a 2005 study by Booz Allen and the Duke University CIBER Center which found that of the companies surveyed, 36% sent some of their engineering work offshore, 31% offshored some R&D, and 16% used offshoring for a portion of their product design. The report points out that to date, offshoring of innovation services has been largely done by advanced countries and that low-cost countries account for about nine percent of worldwide spending on engineering.[192]

The CIBER study looked at worldwide demand for engineering services offshoring in five sectors which make up a high percentage of global engineering spending: automotive, aerospace, high-tech/telecom, utilities, and construction/industrial. Among the service offerings examined were product and component design, plant design, process engineering, and plant maintenance and operations. Tactical versus strategic strategies behind offshoring were outlined. Offshoring as a tactical tool to cut costs, as exemplified by General Motors, was contrasted with the more strategic approach of Toyota which utilizes offshoring as a way to open up new markets, improve quality and overall productivity, and eventually to facilitate innovation. The narrowing of the cost differential between professionals in advanced and developing countries that is now taking place is noted. Finally, it is pointed out that there are significant differences between engineering services offshoring (ESO) on one hand, and business process offshoring (BPO) and information technology offshoring (ITO) on the other. Engineering services offshoring requires more specialized expertise and there is less margin for error in meeting client demands. Thus, anticipating human resource demands and skills required is not easy.

c. India's Value Proposition: Advantages and Challenges.

These two sub-sections discuss the strengths that India brings and the challenges that India faces in expanding its engineering services outsourcing activity. Heading the list of strengths is "the widespread availability of highly skilled, English-speaking engineers. At present, India accounts for 28 percent of all of the available ESO and BPO talent in low-cost countries.[193] The next largest sources of low-cost supply, Russia and China, contribute only 11 percent and 10 percent, respectively."[194]

Other strengths mentioned include the confidence-boosting, strong track record of Indian vendors in BPO and ITO. It is likely that many of these vendors will move into ESO work. Delivery models are well established, quality control can be maintained at high levels, and an example is given in which Indian ESO partners of an automotive Tier 1 supplier produced a dramatic increase in "first-time-right" designs over a three-year period.[195]

"If it is handled well, India's share of the global ESO market could take off at the same time as worldwide demand for ESO increases. India has the potential to control 20 to 25 percent of the global market for offshored engineering services by 2010. By 2020, that number could be 25 to 30 percent, or $50 billion of the expected $150 to $225 billion market. Of India's total market share in offshored engineering services, High Tech/Telecom will likely represent the largest slice, capitalizing on India's existing relationships and expertise. Automotive will most likely be the second largest sector." The report summary describes in more detail the average number of years of experience that ESO vendors and engineers have in six industry groupings. The extolling of advantages for India in ESO ends by stating that the growing economic strength of the overall Indian economy—with a projected GDP 2.5 times the current size by the year 2015—can serve as a spur to policymakers and companies to facilitate and expand Indian ESO activity as a way of gaining access to the Indian market.[196]

A major challenge faced by India is cultivating the necessary engineering talent. "Right now, approximately 35,000 engineers work in engineering services. By 2020, India could need as many as 250,000 to truly reach is potential in terms of market share. While India is already the largest producer of engineers suitable for BPO and ESO outsourcing among other low-wage countries, it will not have enough trained professionals to handle the projected volume of work as the ESO space develops." The Executive Summary of the report goes on to scrutinize the number of engineering schools and the suitability of the graduates for ESO work. Shortages are described as likely to be "especially acute" in sectors other than "High-Tech/Telecom." The contrast is drawn between BPO and ESO in that the latter requires a good grasp of engineering fundamentals, which many working in BPO do not have or need. "Effectively, this means that the number of graduates suitable for ESO work today is actually a small percentage of today's 220,000 graduating engineers. Even in the most popular sector, High-Tech/Telecom, shortages are expected."[197]

According to the Executive Summary, India has a weak physical infrastructure relative to other key Asian countries and that of five infrastructural elements—roads, ports, air, telecom, and speed and cost of Internet access—only India's telecom infrastructure can be considered adequate. This infrastructural weakness could hurt their plans to expand ESO activity. India lags well behind China, their largest potential competitor for ESO business, in roads, airports and telecom, as well as in the strength of their manufacturing base. However, India's advantages include stronger "English language skills, cultural compatibility with the West, a robust political and legal system, and relatively strong protection of intellectual property."[198]

d. "Go Get Forty!" Conclusions.

Some options for India are laid out as to how to proceed to develop the market of engineering services offshoring. "At one end of the spectrum, it can choose to do nothing, and simply rely on growth driven by existing momentum. In this instance, India is only estimated to capture an additional $3 to $5 billion of the engineered-services market by 2010, as opposed to the $13 billion it could achieve; by 2020, this passive growth will achieve $6 to $9 billion instead of meeting India's potential of $35 to $50 billion."[199]

Fixing on a target of $40 billion for Indian ESO by 2020, Booz-Allen outlines in some detail a major effort that would be required to meet this target. There are six elements to this effort which are sketched in some detail: (1) build an "Engineered in India" brand name; (2) improve domain expertise; (3) focus on the creation of infrastructure; (4) improve the workforce in terms of quality and quantity; (5) align government priorities with business development; and (6) leverage local business and local demand. This is no small undertaking. Among the requirements for a $40-$50 billion ESO industry in India are five to seven or more "Bangalore-class" cities. A vast new investment in engineering education is called for as well as "more educational opportunity at every skill level—from primary school education to sector-specialized PhDs." At one point, the report summary indicates that there are 250,000 jobs at stake in achieving the target.[200]

The concluding section of the Executive Summary indicates that India must move quickly of it wants to get into the emerging ESO market. In High-Tech/Telecom, the authors forecast that <u>within one to three years, multinationals will begin to look for partners for developing their high-end engineering projects</u> (emphasis added). For other sectors, the equivalent timeframes are three to five years for Automotive and six to ten years in other sectors before ESO matures. The authors emphasize that the ESO market will become more difficult to go into over time because cost will be less likely to be the main factor in deciding where to source an ESO project. Also, in India's case, the stakes are particularly high for the following reason. "Current service relationships in BPO and ITO could well be impacted if India fails to help its engineers further ascend the value chain. If BPO and ITO are seen merely as cost-saving commodities, sooner or later, outsourcers will look elsewhere for a lower price. To maintain their current hard-won relationships, vendors will need to add more value—the kind of value that a mature engineering services provider will be able to offer."[201]

3. Some Concluding Remarks.

I think this is a very important study. It would be well worth the expenditure for NAE to purchase the complete report. It contains important information about the Indian industrial and educational engineering sector. And it unveils an ambitious plan for greatly expanding Indian ESO activity. It thinks big, which is something that may very well be lacking closer to home about engineering services. Having said that, it probably needs to be viewed through a more skeptical lens than I have provided. Both Booz-Allen and NASSCOM are not necessarily disinterested parties in seeing ESO in India expand.

One particularly intriguing paragraph appears in the subsection on aligning government priorities with business development. It reads: "The (Indian) government could also help in managing a potential backlash against protectionism in other markets as well as domestic jealousies of the ESO industry's special status. In dealing with other governments as well as domestic opponents, it would be helpful to emphasize that unlike BPO and ITO, the expansion of India's ESO sector would serve not to shift jobs from high-cost to lower-cost markets but to actually multiply the number of jobs. Sharing that economic insight could go a long way toward stifling criticism at home and abroad."[202] The report summary simply asserts this good economic news without providing any basis for its validity. One does not need to be a skeptic by nature to question this assertion.[203]

N. Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks

In July 2006, the East West Center released a report by Dieter Ernst entitled *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks*.[204] Ernst is a Senior Fellow at the Center who has done extensive research and writing about offshoring. In an earlier wire story from the East-West Center dated April 7, 2004, the following statement summarizes one very important aspect of offshoring activity as follows:[205] "Ernst said much debate in the media has focused on software outsourcing and call centers moving to India but "that's just scratching the surface" of a very complex issue. Much more important is the relocation of well-paid jobs in engineering, product and process development, system integration and standard-setting. Case studies show that this globalization of knowledge work takes place across a wide range of industries such as computers, semiconductors and telecommunications, as well as chemical engineering, textiles and food processing."

The July 2006 report focuses on the offshoring of elements of innovation and the innovative process to Asian countries. According to Ernst:

"Innovation offshoring has created a competitive challenge of historic proportions for the United States…. (It) poses a fundamental challenge to U.S. technology leadership, economic growth and prosperity. However, the United States still lacks a realistic long-term strategy to respond to Asia's rise as an important location for innovation offshoring." Ernst goes on to point out, however, that: "The simple metaphor—Asia's rise versus America's decline—is clearly misleading. There is no threat to U.S. technology leadership, at least for now. … Nevertheless, there are reasons to expect a longer-term erosion of the U.S. leadership position. There is a real danger that Asia's rise as an important location for innovation offshoring may challenge international trade and investment. It is thus time to accept that the United States no longer is preordained to lead the world in innovation."[206]

Ernst calls for the development of "a new, integrated national strategy on innovation" based upon a dialogue that deals with the challenges of the talent pool, markets, innovative capabilities, national research priorities, and new competitors. He wants consideration of which of three possible scenarios might dominate the division of labor in innovation between the U.S. and Asia in the future:

"<u>Hierarchical</u>: The United States can sustain selective and tightly controlled offshoring of lower-end innovation tasks and responsibilities.

<u>Complementary</u>: U.S.-led global innovation networks combine system integration capabilities in the United States with lower-cost offshore development of intellectual property.

<u>Unequal interdependence</u>: There will be coexistence of architectural innovations and new standards developed both in the United States and in Asia, but the United States will continue to shape the terms of interdependence."[207]

Ernst concludes with several policy suggestions recommendations which he believes highlight a small number of critical challenges for policymakers.[208] Included are the following:

1. Improve Data Collection and Access.

Among other things, Ernst points out that "there is a glaring lack of statistics on how many R&D jobs have been offshored from the United States to Asia and in what industries." Quoting from a recent National Bureau of Economic Research Report that "the U.S. government does not measure the number of jobs offshored," he goes on to point out that this makes it difficult to craft sound policies to cope with the negative aspects of innovation offshoring. Furthermore, he believes that an international organization should be entrusted with the task of data collection pertaining to worldwide markets for global workers.

2. Support Policies for Corporate Innovation.

Two categories of policy responses are discussed in this section of the report, tax policies and intellectual property rights. Two recommendations by the Council on Competitiveness are quoted as being good examples of what is needed in tax policy: a 25 percent federal tax credit for early stage investments when made through qualified angel funds, and a restructured, permanent R&D tax credit which also extends to research conducted in university-industry consortia. Concerning intellectual property rights (IPR), Ernst quotes some reforms of the U.S. patent system recommended by the National Research Council and then goes on to say that they are not enough. Pointing to the difficulties posed by the "anti-commons problem," he believes that meaningful reform of the U.S. IPR regime will be very difficult.

3. Upgrade the U.S. Talent Pool of Knowledge Workers.

Ernst provides a thoughtful, detailed analysis of this subject. He starts by listing three challenges: Provide incentives to increase the number of S&E graduates in the United States. Complement formal education in S&E with "soft" capabilities such as entrepreneurship, knowledge integration, and multidisciplinary and cross-cultural management. Encourage skilled foreigners to continue immigrating and reduce possible negative impacts on U.S. knowledge workers.

a. Provide Incentives to Study Science and Engineering.

Among the many important topics covered in this section are the relatively low salaries of scientists and engineers compared with MBA and law graduates, the negative effect of increasing job insecurity due to offshoring of engineering jobs on young people contemplating careers engineering, and the recent decrease in the number and increase in the proportion of rejections visa applications to foreign students, foreign scholars and high-tech workers. Two avenues Ernst recommends are:

Develop Complementary Soft Capabilities. He argues that formal S&E higher education that focuses on the science and technology is not enough. He quotes from Donald Norman, author of the book *The Invisible Computer*, "The technology is the easy part to change. The difficult aspects are social, organizational, and cultural."[209] And Ernst cites Lester and Piore who point out that U.S. S&E education is excessively specialized and focused on analysis, while neglecting aspects of importance to innovation, such as interpretation, knowledge integration, uncertainty and unpredictability.[210] Also of great importance are international knowledge and intercultural communication skills, which U.S. students tend to lack compared with other countries. "In short, S&E students need training in business, an understanding of international law and business, and an understanding of how to manage, or at least how to work effectively within global production and innovation networks. This requires a multi-disciplinary approach to education instead of majors that are narrowly defined by (frequently outdated) measures. It also requires strong knowledge-integrating capabilities, not just analysis."[211]

Encourage Skilled Foreigners to Continue Immigrating. Ernst begins by stating that immigration of skilled foreign knowledge workers is a contentious issue. He tends to side with industry associations and large research universities in supporting efforts to increase immigration. He argues that policies to restrict entry to the United States through visa restrictions "provide a powerful incentive for U.S. high-tech firms to accelerate innovation offshoring," as a way to acquire access to needed knowledge workers. He does give some attention to the counter argument that the current H1-B and L-1 visa regulations are being utilized to bring in cheap foreign workers to replace Americans. As a way of reconciling this difficult issue, he believes that not only must the United States encourage continued immigration, but must also develop and implement policies aimed at reducing possible negative impacts on U.S. workers, thus providing "the best argument against protectionism and restrictions on immigration."[212]

One question that arises in my mind, as I think about the situation of U.S. engineers who may have been negatively affected by immigration, is: Can these two aspects—immigration and its possible negative impact on the domestic workforce—be linked so that policies to provide significant help to U.S. workers are not simply given lip service?

4. Adapting to the Blurred Boundaries of Innovation.

Ernst believes that his paper "demonstrates that innovation offshoring doesn't have to be a zero-sum game." Among other things, it creates new opportunities for both the United States and for U.S.-Asia relations. Asia benefits by "exposure to leading-edge innovation management approaches and improved access to critical technologies (which) have enabled Asian firms to strengthen their innovative capabilities. Consequently, they have been able to enhance their competitive position in international trade and in the global markets for technology and knowledge workers." Ernst states that if the argument of many economists that global welfare benefits from Asia catching up to the United States is correct, U.S. corporations that employ foreign knowledge workers at home or abroad will be the big winners. "By investing in offshore R&D labs, these companies are able to substantially reduce the cost of U.S.-based scientists and engineers but also gain access to complementary innovative capabilities. Furthermore, innovation offshoring helps U.S. companies to penetrate the growing and increasingly sophisticated markets of Asia."[213]

"As Asian countries improve their innovative capabilities, the U.S. share of global inputs in the innovative process—such as R&D spending, knowledge workers, and the quantity and quality of scientific literature—will gradually decline. Yet, the policies described in the preceding sections can help ensure that this does not translate into a sudden weakening of the

U.S. innovative system and its capacity to produce significant innovation outputs, such as the quantity and quality of patents and market-defining standards."[214]

Ernst finds reason for cautious optimism with regard to U.S. innovation prospects, provided that a new national strategy with appropriate policies is implemented. Whether in fact that will happen is an open question.

O. Complexity and Internationalization of Innovation: Why is Chip Design Moving to Asia?

Ernst had a paper published in March 2005 with the title given in the heading of this subsection.[215] The journal issue in which it was published was dedicated to Keith Pavitt, a distinguished scholar in innovation who spent many years at the Science Policy Research Unit (SPRU) at the University of Sussex in the United Kingdom. Ernst begins by pointing out that one of Pavitt's many contributions to innovation research was his conclusion that "physical proximity is advantageous for innovative activities that involve highly complex technological knowledge. Cognitive and organizational complexity explain why innovation is an important case of non-globalization."[216]

"Following this argument, one would expect a highly complex innovative activity like chip design—a process that creates the greatest value in the electronics industry—to be spatially immobile, much less prone than manufacturing to geographic relocation. Until quite recently, chip design has indeed remained heavily concentrated in a few centers of excellence, mainly in the US, but also in Europe and Japan. However, fundamental changes have occurred over the last few years in the location of chip design that are signaling a growing geographical mobility. Of particular importance has been a massive dispersion of chip design to leading Asian electronics exporting countries."[217]

Ernst's paper goes on to explore why, contrary to what might have been expected from previous theoretical work, very complex chip design work is moving to Asia. He uses Pavitt's framework to provide new insight into the relationship between the internationalization of innovation and complexity, interviewing 60 companies and 15 research institutions in four Asian countries (Taiwan, Korea, China, and Malaysia) and the United States that are active in electronic design of both integrated circuits and systems. He utilizes three categories for analysis: "pull," "policy," and "push factors." "'Pull factors' are demand-oriented and supply-oriented forces that attract chip design to particular locations. 'Policy' factors are policies and regulations in both home and host countries that affect differences in the cost of conducting innovation across locations." Finding these two factors important but not sufficient, he goes on to focus on "'push' factors, i.e., changes in design methodology ('system-on-chip design,' or SoC) and organization ('vertical specialization' within global design networks, or GDNs), and explores the pressures and opportunities that these changes provide for the internationalization of design. Vertical specialization within GDNs implies that stages of chip design are outsourced to specialized suppliers (disintegration of design value chain) and relocated across national boundaries (geographic dispersion). The resultant increase in knowledge mobility explains why chip design that in, Pavitt's framework is not supposed to move, is moving from the traditional centers to a few new specialized design clusters in Asia."[218]

In a concluding section, Ernst focuses on why chip design, highly complex though it may be, can now be carried out at multiple locations. "…(C)hanges in the methodology and organization of chip design that were introduced to improve design productivity, instead have further increased the cognitive and organizational complexity of design. In response, vertical specialization within GDNs (global design networks) has been pushed deeper and deeper into the design value chain. In contrast to earlier expectations of arms-length, 'frictionless' contracting in chip design, I show that GDNs are long-term arrangements that are shaped by corporate strategies. Initially, this has loosened the bonds between design and fabrication.… Over time, however, vertical specialization has increased the number and variety of GDN participants, business models, and design interfaces, bringing together design teams from companies that drastically differ in size, market power, location and nationality. This has dramatically increased the organizational complexity of these networks—GDNs must simultaneously coordinate multiple communication and knowledge interfaces."[219]

"The paper demonstrates that, as SoC (system-on-chip) design requires a large number of designers with highly diverse capabilities, geographic proximity can become a disadvantage (emphasis added). I document pressures and opportunities that vertical specialization has created for GDN participants to relocate design to Asia, highlighting specifically the increasing importance of software design, as well as changes in skill requirements and in design work optimization."[220]

1. Some remarks.

I am not a chip design expert. I have generally tried in my paper not to look at specific technologies but to leave that to the industry/sector specific authors. However, Ernst's work on chip design strikes me as being particularly important. Here is a case where innovation theory would lead one to believe that chip design would not be a tradable or offshorable activity. Reality is proving otherwise. Now, as has happened before, theory needs to catch up. Ernst finds Pavitt's case for proximity and co-location of innovation to "remain as powerful as ever." However, he has uncovered new evidence that needs to be dealt with. In Ernst's words, "…we need to explain what makes it possible to exchange complex knowledge even if innovation agents are located at distant locations."[221]

P. Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?

Richard Freeman raises this question in the title of his Working Paper published by the National Bureau of Economic Research in June 2005.[222] Freeman is one of two presenters at the forthcoming NAE Workshop on Offshoring of Engineering in the session on the Engineering Workforce and the Profession. Therefore, I will not carry on at great length about his paper here. Freeman's work is important and relevant to Workshop deliberations. Hopefully, he will update his analysis to present conditions.

Freeman abstracts his paper as follows:[223]

> "This paper develops four propositions that show that changes in the global job market for science and engineering (S&E) workers are eroding U.S. dominance in S&E, which diminishes comparative advantage in high tech production and creates problems for American industry and workers:
>
> (1) The U.S. share of the world's science and engineering graduates is declining rapidly as European and Asian universities, particularly from China, have increased S&E degrees while US degree production has stagnated.
>
> 2) The job market has worsened for young workers in S&E fields relative to many other high-level occupations, which discourages US students from going on in S&E, but which still has sufficient rewards to attract large immigrant flows, particularly from developing countries.
>
> 3) Populous low income countries such as China and India can compete with the US in high tech by having many S&E specialists although those workers are a small proportion of their work forces. This threatens to undo the "North-South" pattern of trade in which advanced countries dominate high tech while developing countries specialize in less skilled manufacturing.
>
> 4) Diminished comparative advantage in high-tech will create a long period of adjustment for U.S. workers, of which the off-shoring of IT jobs to India, growth of high-tech production in China, and multinational R&D facilities in developing countries, are harbingers.
>
> To ease the adjustment to a less dominant position in science and engineering, the U.S. will have to develop new labor market and R&D policies that build on existing strengths and develop new ways of benefitting from scientific and technological advances in other countries."

One important characteristic of Freeman's paper is that he took the time to look carefully at data available on the scientific and engineering workforce from NSF and other national data bases. His work emphasizes the importance of R&D scientists and engineers (S&Es) in the defense industry, the very significant and increasing role of foreign-born individuals in the S&E workforce which increases as the educational level increases, the strong motivation of immigrants to pursue S&E careers in the U.S. compared with native-born citizens who have more options and find other career paths more appealing and potentially rewarding, and the fall-off in the share of scientific papers produced by the United States. One possible pitfall here and elsewhere in his paper for our purposes is that Freeman mostly lumps scientists and engineers together and some of his observations, like the latter may be more relevant for scientists, say, than for engineers.

Freeman looks at the job market for bachelor's and master's graduates, observing that most S&E jobs in industry are held by engineers with bachelor's degrees. He comments on the rise in unemployment in 2003 for electrical and electronics engineers and questions the strength of the job market after that when unemployment rates for that occupational grouping fell. Even though engineers who find new jobs may do so fairly quickly, some may find it outside their chosen field and, chances are, at lower wages. He comments on the sharp reduction that took place between 2000 and 2002 in BLS projections for the growth rate of employment for computer specialists, attributing it to a growth in offshoring. The changed projection lowers the number of jobs for computer specialists over the next decade by about a million. Elsewhere in this paper (See Section IA3), I have pointed out that the more recent BLS projections that show engineers as having the lowest projected growth rates from 2002–2012 than any occupational group.

Freeman attributes the seeming adequacy of the supply of scientists and engineers in the United States to students and workers coming here from other countries. Efforts to attract more U.S. citizens to these fields must deal with the diminished appeal and rewards for U.S. entrants compared with other professions. And heavy reliance on a continued healthy flow on foreign born S&Es is not without its perils. He also introduces the possibility of "human resource leapfrogging," in which China and India with growing numbers of S&Es are able to employ sufficient numbers back home to complete with the United States and European Union countries in leading-edge technology sectors.

Returning to the title of his paper, although he thinks that a definite answer is premature, Freeman concludes that several indicators appear to point to a threat to the United States in its role as technological and economic leader. These indicators include new R&D facilities being opened in China and India by high-tech industry leaders, the offshoring of certain forms of skilled jobs, big gains in China in technological capability as measured by various indices (publications, patents, "Technological Standing" Index), and in Chinese production and global market sales increases.

Freeman anticipates that as numbers of S&Es in foreign countries increase, the United States will lose some of its comparative advantage in generating S&E knowledge; hence, products sold in high-tech sectors by the United States will decline. He sees this as being of benefit in raising incomes in low-income countries while also benefiting the United States through worldwide advances in new knowledge, resulting in reduction in costs. However, he provides this warning:

> "…(T)he US will also face economic difficulties as its technological superiority erodes. What is good for the world is not inevitably good for the U.S. The group facing the biggest danger from the loss of America's technological edge are workers whose living standards depend critically on America's technological superiority (emphasis added). The decline in monopoly rents from being the lead country will make it harder for the US to raise wages and benefits to workers. The big winners from the spread of technology will be workers in developing countries, and the firms that employ them, including many U.S. multinational corporations. In the long term, the spread of knowledge and technology around the world will almost certainly outweigh the loss of US hegemony in science and technology, but the transition period is likely to be lengthy and difficult—more formidable than that associated with the recovery of Europe and Japan after

> World War II. The more similar the production technologies and composition of output in lower wage countries becomes to that of the US, the greater will be the downward pressures on US wages."[224]

Freeman concludes by considering new policies that the United States will have to look at to adjust to these difficulties. Among these are policies that (1) encourage substantial numbers of students and workers from other countries to come to and stay in the United States; (2) seek to increase the supply of U.S.-born S&Es through larger numbers and better paying graduate fellowships; (3) increase government R&D spending on R&D; and (4) strengthen industry-university collaboration. He also points out that, although the United States benefits from the relatively high mobility of its workers, it does not have a good "social insurance system" for helping workers handle a lengthy transition period. Compared with other advanced countries, the U.S. health insurance system tied to employers is the most expensive and the "safety net" for workers provides the least safety. Unfortunately, he does not provide specific steps to indicate how the social insurance system might be improved.

Q. Take This Job and Ship It

In 2006, Senator Byron Dorgan of North Dakota takes aim at offshoring in his book *Take This Job and Ship It: How Corporate Greed and Brain-Dead Politics are Selling Out America*.[225] Dorgan's book is a critique of offshoring, within the broader context of trade and other policies which he believes are hurting American workers. He sees offshoring as being particularly damaging to unions, as contributing to the weakening of the U.S. manufacturing and high-tech base, as putting downward pressure on wages, and as having national security implications. He asks: "Is profit the only motive of corporate decisions? Or does the corporation have some responsibility to workers, too?"[226]

Senator Dorgan points out the downside of recent free trade agreements, arguing that they have led to the loss of U.S. jobs and an increase in the U.S. trade deficit, while at the same time moving plants to other countries that could not meet environmental standards here, as well as resulting in continuing exploitation of workers overseas. In a final chapter, he takes dead aim at Thomas Friedman's book, *The World is Flat*, arguing that it's "just flat wrong![227] The world isn't flat. Our trade agreements aren't fair. And outsourcing American jobs hurts our country."[228] He offers a list of eleven proposals to turn things around, ranging from developing an American Fair Trade Plan to tackling health-care costs and education excellence. One recommendation that seems most directly related to offshoring is to repeal the tax break for exporting jobs. Central to this is his call to change the tax code which now permits corporations doing business overseas to hold off on paying U.S. taxes on the profits until they bring them back home. In 2005, they could do so at a very low 5&1/4% tax rate on repatriated dollars.[229]

Although Dorgan's book cuts a wide swath through a broad range of issues, it is clearly of relevance to the offshoring of engineering and other high-tech jobs. In an early section on "The Attack on White-Collar Workers," he gives the example of Natasha Humphries, an African-American graduate of Stanford who became a senior software testing engineer for Palm Pilot and lost her job after three years when, in 2002, a decision was made to move all product testing to China and India. After she was persuaded to go to Bangalore for two weeks to train Indian workers, and after six subsequent months of mentoring those workers from the United States, Ms. Humphries was laid off in August 2003 in spite of previous assurances by the company that she would not lose her job due to offshoring. Dorgan asks why and answers as follows: "She and her coworkers couldn't work for $2 an hour. So they couldn't compete with the engineers from India." He adds the following post script to Natasha Humpries' story:[230]

"So, we are told that we need to train more engineers here in the United States. But at the same time we had better answer the question about what those engineers can expect when they graduate from college. Is their future competition going to be engineers from India who will work for one-fifth the wages here in the United States? How is that going to work to persuade young men and women to study engineering in colleges?"

Senator Dorgan's book places offshoring within a broad economic and political context. Salaries for all U.S. workers since 1973 present a mixed picture and concerns that the middle class is shrinking are being expressed more frequently.[231] Since 2001, worker income has stagnated and the poverty rate has risen.[232] Loss of U.S. jobs and the difficulty many people have in making ends meet, although perhaps not as high a concern in opinion polls as Iraq, are likely to receive increasing attention in the 2006 elections. Immigration is certainly politically salient and trade policy is coming under renewed scrutiny. Although engineering occupies a somewhat specialized niche in the workforce, the offshsoring of engineering jobs is vulnerable to and a part of this broader context.

R. Offshoring: Three Disciplinary Responses

This section presents responses concerning offshoring of engineering jobs in three disciplines: chemical engineering, biomedical and manufacturing engineering, and optical engineering. The last two contain replies to some of the specific questions that were posed in Section IE of this paper.

1. Chemical Engineering.

I have found little information readily available on the Internet on offshoring of chemical engineering jobs. However, I did engage in E-mail correspondence with John Chen, a former dean of engineering at Lehigh University who is serving as president of the American Society of Chemical Engineers. Here, lightly edited, are some thoughts from Dr. Chen regarding the issue of offshoring of engineering jobs, and consequences for young people's choice for careers:

"a) I can understand why the issue is being raised. Few new chemical plants are being constructed in North America—only 40 out of total of 430 large new plants in the United States in 2005 compared to 70 out of 390 in 1995. It follows that certain types of ChE functions in the United States have been in decline, and will likely continue.

b) However, anecdotal indications are that U.S.-educated chemical engineers are in demand, if they are willing to work out of country. Traditionally, only a small fraction of U.S. engineers are employed in other countries. Only ~2% of U.S.-educated chemical engineers were employed abroad in 2003, compared to 12% for the U.K. and 23% for France.[233] Clearly, there is room for more U.S. chemical engineers to take assignments abroad, though the high U.S. salaries could mitigate this option.

c) The supply/demand market does not show any drop in the competition for U.S. chemical engineers. The latest survey ('05–'06)[234] again indicates that BS ChemEs receive the highest starting salaries of all disciplines. This year has been a stellar year for young ChemEs on the job market. Of course this reflects recent and current status; and there can be concern for the durability of this behavior.

d) As for college enrollments, chemical engineering has been fluctuating around an average which is slightly below its multi-decade national mean. My own guess for the reason is heightened glorification for two competing areas, computer science in the 1990s and bioscience in the 2000s. I also believe that both these waves have passed their crests, so the "traditional" engineering disciplines may be regaining their share of student interest.

e) Finally, I am optimistic that the growing public awareness of the energy challenge, along with the concurrent concern with environmental sustainability, will motivate more and more young people into disciplines which are needed to address these basic society needs. Chemical engineering is surely one of the key disciplines!"

Dr. Chen added the following postscript: "I didn't plan on rambling on like this, but your question triggered a sensitive point for me. I wish there were more data or analysis that can quantify what is currently just 'feelings.' I will be very anxious to read the report from your work."[235]

In a follow-up exchange, I asked specifically if there have been concerns about offshoring of jobs in chemical engineering similar to those in, say, electrical engineering. Dr. Chen's response was as follows:

"There have been some expressions of general concern by chemical engineers, but I have not heard many specific reports of derailed careers due to global outsourcing. It is hard to predict if such will happen. One alleviating factor is that Chem. E's work in so many different industries (chemical process industries, oil, gas, power, environmental, pharmaceutical, electronic, etc.) that such diversity will dampen shocks that occur in any one industry (e.g., the information industry)."[236]

a. Postcript. Where are Chemical Engineers Headed?

I came across (at the last minute) an interesting, relevant article in the August 2004 issue of *Chemical Processing* by Mark Rosenzweig, editor-in chief.[237] It contains the views of a number of leaders in industry and academia as to where the profession is going and what chemical engineers might expect to face in the future. Rosenzweig sees the links between the chemical engineering profession in the United States and the production of chemicals growing weaker with the movement of chemical plant production overseas. Significant shifts are occurring in the sectors and geographic locations in which chemical engineers work. And prospects for careers in the fields of pharmaceuticals, biotechnology and sustainability are beckoning. These developments are reflected in the remarks of some of the people featured in the article and in the interview I had with Dr. Chen.

However, the last two sections of the article, entitled "Outsourcing Gets to the Core" and "Grasping with Globalization" contain some warning signals. Areas of concern that are expressed by some are fewer positions overall for chemical engineers, operating companies going too far in outsourcing and coming close to losing technical core competencies, and a thinning in the ranks of experienced engineers. As the building of chemical plants overseas has accelerated, it has been accompanied by the shifting of engineering design work, stated by some in the article as being or becoming a commodity, abroad in lower-cost countries. Some forecasts for the future are modestly optimistic, particularly if the United States can retain its technological, inventive, and innovative edge. However, Edward Cussler, a senior professor of chemical engineering at the University of Minnesota is less sanguine, predicting that the chemical engineering profession will be smaller 10 years from now. He believes that the largest cutbacks have already taken place or, as he puts it: "The worst is over but the best is not yet to come."[238]

2. Biomedical Engineering and Manufacturing

I received the following replies to some specific questions from Kenneth J. McLeod, professor and chair, Department of Bioengineering, Watson School of Engineering and Applied Science, Innovative Technologies Complex, State University of New York, Binghamton. The questions appear first in italics and Dr. McLeod's replies, lightly edited, follow.

How many U.S. engineers have been negatively affected by offshoring during the past five years or so? Variables of interest include loss of jobs, reduction in salaries, and loss of job security.

"*The Economist* has been following this issue and I would recommend you search their database online. In September 2005, they did a nice summary on the decline of jobs in manufacturing in the developed countries, which is largely the sector where the jobs are being offshored. If engineering positions track manufacturing, then we have seen roughly a 20% decline over the last decade. The extent to which this can be attributed to offshoring vs. improved productivity may be very difficult to say. In any case, we are talking very small numbers (from a national perspective), less than 5% of the American workforce is now involved in manufacturing (~7M out of a workforce of 147M), and that number will likely be cut in half in the next few decades. Engineering positions account for maybe 5% of that number, so we are talking a total engineering workforce in manufacturing of 350,000, which will drop during the next generation to around 100-150,000, so the fraction that is offshored is not going to be a very important issue. <u>The lack of need for traditional engineers will be the big story</u>" (emphasis added).

Has the offshoring of U.S. engineering jobs, either real or perceived, made a career in engineering for young people more or less attractive?

"Engineering has not been perceived as an attractive career for the vast majority of the most talented young people. The exception may be bioengineering, but the numbers are so small they are hard to interpret. First generation college students and immigrants will consider engineering, but the effort/reward ratio is considered far too high by most domestic students (See NAE 2020 report). If we educators do not rapidly adapt to the marketplace and start teaching "engineering" as it will be practiced in the 21st century, I believe we will see progressively less interest in this field. It is time to move beyond teaching the design and manufacturing of artifacts and move toward how we "design" and "build" services, social systems, political systems, healthcare systems, etc. Engineering can play an enormous role in a service economy, but only if we do not restrict our analytical and design capability to mechanical and electrical systems."

Is offshoring of engineering work contributing or does it have the potential to contribute to a significant loss of in-country R&D/S&T capability?

"We will largely see an outsourcing of incremental engineering projects. There is no reason why innovation cannot stay in the country, but we need to make sure we are recruiting and keeping the creative youth of our country in engineering programs. The focus of traditional engineering programs serves to exclude the most talented and creative students, such that they never consider entering engineering, or are washed out in prerequisite courses which have little bearing on whether they would succeed as engineers in the real world."

Has the morale of the U.S. engineering profession been negatively affected by offshoring? Will the psychological and emotional effects of offshoring on the profession contribute to a loss of needed engineering workforce capacity and capability in the future?

"The main theme we try to teach our engineering students is that change is opportunity and that engineers innovate to exploit opportunity. It would more than a bit sad if we turn around and say that because a change is affecting us personally it is demoralizing. If we are true to our profession, this change should be as energizing as any other change that has occurred, and it is incumbent upon us to innovate to make the best use of the new opportunities arising as the developing countries take on the tasks that we used to have to do ourselves."[239]

3. Optical Engineering.

Eugene G. Arthurs is executive director of SPIE, The International Society for Optical Engineering. He provided this characterization of SPIE members: "Although we have 17,500 members, we represent an extremely diverse applications community. Most of our engineer members have advanced degrees and would be involved quite close to the R of the R&D continuum. We do not track employment levels, and the societies with which we are most familiar do not do so either. But I won't go on to whine about the SOC codes and demographic tracking.

What we do note is the huge shift in the geographic origin of papers submitted to our journals. But nothing is simple. Bayh-Dole may have had an impact here also.

Let me also say that perhaps inshoring is the bigger problem for U.S.-born engineers and those naturalized. The question of an infinite supply of cheap engineers is valid, if corporations can keep the pressure on to raise the visa limits. I'm conflicted here, by the way. I sometimes believe that the only way to force us to address our educational system is to cut down the expert visas. However, it might now be too late for this because corporations—and here I do not blame the CEOs who are in the job to do the best for the shareholders, ultimately us with our 401(k)'s etc.—will move to the talent. The economic pain might also be too great, and I say this as a recipient of such a visa and a believer in a global market."[240]

After indicating that SPIE has no good data to provide, and after commenting that he believes offshoring to be a very complex global issue that is all too often reduced to an emotive sound bite, Dr. Arthurs went on to respond to my specific questions as follows[241]:

How many U.S. engineers have been negatively affected by offshoring during the past five years or so? Variables of interest include loss of jobs, reduction in salaries, and loss of job security.

"No hard data."

What are U.S. engineers who lost their jobs to offshoring doing now? Are they employed? Are they still in engineering? How do their wages and benefits before and after they were affected by offshoring compare?

"No hard data. We track the numbers and demographics of our U.S. members, 50% of whom are employed in industry. We also track the U.S. EE degrees to native born and foreign born."

Has the offshoring of U.S. engineering jobs, either real or perceived, made a career in engineering for young people more or less attractive?

"I believe that the public perception of offshoring has made a career in engineering less attractive to young people in the United States and to their parents. There are very large numbers quoted for engineering graduates in countries such as China or India, numbers that dwarf the output of U.S. engineering programs. There are also almost daily reminders of jobs being outsourced to lower cost areas. These media stories form opinions, rather than the actual number of established jobs in the United States or the ongoing location of R&D activities in the United States by foreign companies to avail of closeness to market or the innovative culture.

There is another view of the situation, which to me poses a different threat. There are those who believe that we should not worry as most of the engineers graduating in China and India do not have the skills needed to compete. The McKinsey study, of 2003, I believe, supported this viewpoint. This view reminds me of our dismissing Japan as a nation good only at making cheap plastic copies. That, of course, was before Japan took the bulk of our consumer electronics manufacturing, and well before Japanese companies took the dominant position in patents granted by the US Patent and Trade Office (USPTO).

I believe it is impossible to disentangle the impact of offshoring from a widespread turning from science and engineering as a career in the developed world. I hear that even in Shanghai, the young affluent eschew science. It seems that unless there is no other economic advancement path, science is not preferred. Besides the reality that we have a pathetic image, engineers more so even than mad scientists (what does a schoolchild or their parents really know of engineering?), a high official of a national science educators organization told me she puts some credence in the perception that science is no longer for the good of humanity but for the good of corporations. Sometimes I ask why a smart kid would take up a career path that requires very hard work to reach expertise in a body of work with an ever diminishing half-life, and results in lower rewards (and now uncertainty?) when s/he can go into lawyering or business and have a BMW in short order."

Does the engineering profession provide adequate support for its members who are affected negatively by offshoring? If not, what additional support should be provided?

"No. It is a market economy. There is lots of talk of retraining that I believe is pie in the sky. It is much easier to open a small franchise business than compete with the young newly skilled."

Is offshoring of engineering work contributing or does it have the potential to contribute to a significant loss of in-country R&D/S&T capability?

"I believe so. Again as a CEO, why would I locate my R&D center here if I can get lower costs elsewhere? There is much comfort taken in the lack of entrepreneurial skills and mindset inherent in say the Chinese educational system. I have no doubt that this extraordinary people will figure that one out soon. Perhaps this is not so for other countries. (Friedman has done something of a reversal on China here with his 'never count on a country that censors Google.')"

Has the morale of the U.S. engineering profession been negatively affected by offshoring? Will the psychological and emotional effects of offshoring on the profession contribute to a loss of needed engineering workforce capacity and capability in the future?

"Yes. Unequivocally."

S. Is Offshoring Accelerating?

In the course of writing this paper, I have come across many articles about U.S. companies expanding their operations overseas, and/or closing or cutting back facilities at home. I did not try to systematize or quantify them. Nor did I attempt to figure out how many jobs were offshored as a result of specific moves. However, the picture these articles paint is of a phenomenon that is gaining momentum, not only in large companies but small ones as well. Here I will briefly summarize some of these recent actions.

January 7, 2005. Deere & Company announced plans to expand its operations in Pune, India, by opening a business processes and engineering center later in 2005. The facility, which will start up with roughly 100 employees, will provide IT and engineering support services for Deere's global operations. They currently have a tractor manufacturing joint venture with Larsen & Toubro Limited in Pune.[242]

June 7, 2006. IBM announced it will triple its investment in India over the next three years to nearly $6 billion. The company now has 43,000 employees in India, more than anywhere outside of the United States. They are expanding, according to IBM executives, not only because of inexpensive Indian engineers but also "because of the quality of their work and their ability to come up with fresh products and services."[243]

August 2, 2006. Electronic Data Systems (EDS) announced an accelerated shift of its workforce from the developed world to low-cost countries. EDS plans to bring its workforce up to 45,000 in "low-cost centres" within the next "couple of years," an increase of 50%. At the same time, more than 15,000 jobs will be lost in the United States and other developed countries.[244,245]

August 9, 2006. Computer Sciences Corporation (CSC) announced plans to cut approximately 1,800 jobs by 2008 in North America while hiring about 2,000 workers in low-wage countries like India during the same time period. CSC is the third-largest outsourcing company and it has billions of dollars of technical IT services contracts with the U.S. government.[246]

September 8, 2006. Intel announced it was cutting 10,500 jobs, about 10 percent of its workforce. This came in spite of Intel having benefited greatly from the American Jobs Creation Act which enabled U.S. corporations operating overseas to repatriate $6.2 billion at a foreign profits tax rate of only 5.25% rather than the normal 35%. A major purpose of the Act was to generate revenue so that companies would create new jobs in the United States.[247]

September 16, 2006. Ford Motor Company announced an accelerated turnaround plan that would cut one-third of its white-collar jobs and shut down or sell off more plants. Some 14,000 white-collar positions would be eliminated through early retirements, voluntary separations and, if necessary, involuntary separations. In addition, buyouts will be offered to 75,000 hourly workers. Ford's move comes on the heels of reductions it announced in April, 2006. General Motors has also taken similar steps to cope with severe financial losses.[248]

September 18, 2006. WebMethods, a relatively small (840 employee) technology firm, recently purchased Infraovio, an even smaller company headquartered in California that has 50 software developers on its 65-person staff located in Chennai, India. In a *Washington Post* article entitled "Smaller Firms Buy Overseas Shops," Kim Hart writes that: "While large technology companies have been moving research and development resources overseas for nearly a decade, such outsourcing has also become important for small and mid-size software firms." Among the drivers for this activity is the desire of these firms to cut costs by moving R&D offshore. Venture capital is encouraging this movement by making it a condition for U.S. firms to receive funding.[249]

T. Penultimate Thoughts from Martin Kenney

I recently had an E-mail exchange with Martin Kenney, who with Rafiq Dossani co-authored the lead article in the fall 2005 issue of the NAE *Bridge* that was described earlier in this paper. I inquired if Prof. Kenney was doing any current work to track, in a systematic way, articles and other information on the offshoring of engineering and other high-skill work and jobs by U.S. companies. I also asked if he had been able to sum up quantitatively what he had found and to assess the cumulative implications for the U.S. engineering workforce and profession. Finally, I inquired if he had any thoughts to offer about the six specific questions I had sent out to representatives of professional engineering societies. His responses, quoted below were both informative and somewhat sobering.[250]

"We have been downloading job descriptions from six U.S. firms' websites in India for 18 months. We have also been downloading articles on employment by U.S. firms in India to try and develop time series of employment abroad. However, there are no systematic studies available on the number of jobs offshored.

I know of no serious studies that answer the questions you have posed. All we have are estimates. My gut feeling is the McKinsey Global Innovation (MGI) study of unique industries that was issued last year is the best available. My most recent work is the Country and Firm chapters in the ACM report for which I was the main author.

There are no quantitative studies and likely there never will be because it is almost impossible to get one to one matches. In many cases, automation may be as important at eliminating jobs as offshoring and it is difficult to separate the two effects. We have given up on this and are simply trying to figure out how global headcounts are changing in specific firms and what is being done in offshore low-wage countries.

The bottom line is that all routinized engineering work (and some not routinized work) is at risk (emphasis added). Jobs will be the most protected in which learning and interacting occur intensively with lead customers that are in highest density in developed nations. Also, although entrepreneurship can happen anywhere, in munificent environments in developed nations it should be easier, thereby providing opportunities for our well-trained engineers. Then, these new firms will grow very quickly initially here (core team), though these firms also may start offshore operations very early."

U. Concluding Remarks

A lot has happened in the world of offshoring since I last looked at it in any detail almost three years ago. Much has been said and written. My overall assessment of offshoring's impact on the engineering workforce and the profession is as follows.

Offshoring of engineering jobs has continued to gain momentum. Companies are moving up the scale by offshoring more higher-skill technology jobs. In engineering, more is written and said about offshoring in the IT, CS and EE fields than other disciplines. However, it is likely that all disciplines are being affected to some degree, as material about mechanical, civil, and chemical engineering indicates.

The current situation appears to have improved somewhat for U.S. engineers who were caught in the double whammy of the most recent business downturn plus offshoring. However, much is unknown about those who were impacted and what they are doing now. Some who managed to stay in engineering had to take salary cuts. Others retired or sought employment outside of engineering. Concerns in the engineering profession about decreasing job security and job satisfaction remain evident.

There have been some recent efforts to try to learn more about offshoring, including a study[251] by the Services Offshoring Working Group at MIT, with support from the Alfred P. Sloan Foundation and Rockefeller Foundations. However, much more needs to be done, particularly related to offshoring of engineering jobs and services. Most studies are broad in scope and do not hone in on the problems and challenges that offshoring presents for the engineering workforce and profession.

Offshoring remains a major concern for the engineering profession. Although engineering bachelor's degrees awarded and the percentage of engineers who are employed may have recovered somewhat in the last year or two, my impression is that the future of the profession is murky. There is enough information out there to indicate that many are questioning whether engineering remains a secure, satisfying and financially rewarding profession in the era of globalization and offshoring. And some are passing their concerns about engineering on to their children and grandchildren in the form of career advice that does not bode well for engineering.

A persistent problem that I have run into over the past 40 years is that there is no focused, continuing effort to examine the engineering profession as a whole—it's structure, components, nature, health, problems, opportunities, and it's evolving societal role. This problem has been exacerbated by the fractured nature of the profession which has suffered from not having strong central leadership and a sense of not being truly a profession. Because of this lack of focused, continuing effort, we do not have a centralized source of data and information to call upon when issues of major importance to the engineering profession arise, as is the case with offshoring. Some of the data are out there but it is scattered hither and yon. Other data are missing. And analyses of important issues facing the profession, the kind that a few dedicated centers devoted to the study of the engineering profession could provide, are not abundant. **We need a Center for the Study of the Engineering Profession.**

Although it is not in the purview of this paper, I will comment briefly on the implications of offshoring for U.S. engineering education. It struck me this time around that the key reform we need is to stop viewing engineering as being almost exclusively a technical profession, one deeply absorbed with utilizing the materials and forces of nature to the exclusion of most everything else. We need to emphasize people skills and communication within an international context. We need to give our students a strong sense of what they are likely to run into during a career in engineering and the kind of attributes that might be needed to succeed—I say 'might be needed' because there are no guarantees. The world has changed a lot and change seems to be accelerating rapidly.

I have devoted a fair amount of attention to engineers who have been affected negatively by offshoring. Their concerns are not likely to be addressed by better data and statistics. I am struck by the inability of leaders in government, academia, and industry to involve in their deliberations working engineers as well as those who have had to abandon their chosen profession. Government policy, heavily shaped by corporate inputs, has a profound affect on offshoring and its positive and negative consequences. I do not profess to know the answers as to what the right policies on offshoring would look like. There are a variety of views out there (see, for example, Hira in Section IIIG2d) and I have not given them enough attention in this paper. A logical follow-on to the October NAE Workshop is one devoted to policy responses to offshoring of engineering jobs, one that involves working, disaffected and prospective engineers. If I still ran an academic science and technology policy program and research center, I might propose one myself.

One important policy issue that needs much more attention is the matter of what can be done to ameliorate, if not prevent, the negative impacts of offshoring on affected and future engineers. There appears to be considerable sentiment from people with differing views on offshoring that appropriate responses to this issue are called for. Job retraining, wage insurance, trade adjustment allowances, portable health insurance, reasonable severance packages, a greater sense of responsibility by corporations towards their workers, a stronger role for engineering professional societies, and greater involvement in unions are just some of the varied responses out there. However, it is one thing to suggest something and another to make it happen. All or nearly all of these suggestions appear to be far from receiving detailed, serious consideration and evaluation by policymakers at the present time.

This journey through the realm of offshoring of engineering jobs turned out to be much more complicated and time-consuming that I had envisioned at the outset. Because I am still in the process of forming and sharpening my views about them, I have not attempted here to answer directly the key questions I posed in Section IE. Perhaps additional responses and data might be obtained by distributing these questions to the participants at the October NAE Workshop on engineering offshoring.

The forthcoming NAE Workshop on the Offshoring of Engineering on October 24–25, 2006, provides a golden opportunity at the right point in time to look hard at what offshoring has done to and means for the future of the engineering profession and its various sub-sectors. I am pleased to have been able to view the plans for the Workshop as they have developed, and to have played a role in its creation.

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I am solely responsible for the contents of this paper. Hopefully, it will do some good.

Robert P. Morgan
September 22, 2006

W. References and Notes

[1] Morgan, R.P., "Global Outsourcing of Engineering Jobs," A Working Background Paper prepared for the Program Committee Meeting of the National Academy of Engineering on October 10, 2003.

[2] Hira, R., and A. Hira, "Outsourcing America: What's Behind the National Crisis and How We Can Reclaim American Jobs," American Management Association, 2005.

[3] U.S. Government Accountability Office, "Off-shoring of Services: An Overview of the Issues," Report GAO-06-5, November 2005.

[4] "Off-Shoring: An Elusive Phenomenon," A Report of the Panel of the National Academy of Public Administration for the U.S. Congress and the Bureau of Economic Analysis, January 2006.

[5] Friedman, T.L., "The World is Flat: A Brief History of the 21st Century," Revised Edition, Farrer, Strauss and Giroux, 2006.

[6] Friedman, T.L., "Outsourcing, Schmoutsourcing! Out is Over," *New York Times*, May 18, 2006.

[7] IEEE-USA News Release, "Offshoring is Major Cause of Technical Unemployment, IEEE-USA Survey Reveals," March 8, 2005. See also Langbein, L., "2004 IEEE-USA Unemployment Survey Results (11/29/04)."

[8] Harrison, R., "Employment Data Paints disturbing Picture," in IEEE-USA's Today's Engineer Online, September 2005.

[9] Holmes, Kathryn to Robert P. Morgan, E-mail. June 28, 2006.

[10] See Refs. 3 and 4. Also, Sturgeon, T.J., et al., "Services Offshoring Working Group: Final Report," Industrial Performance Center, MIT, September 10, 2006.

[11] Florman, S.C., "My Profession and My Nation: A Worrisome Confrontation," The Bent of Tau Beta Pi, Summer 2005, pp. 15–16.

[12] Ibid. p. 15.

[13] Questions 7 and 8 are paraphrased and/or derived from correspondence with Sam Florman.

[14] Two that come to mind, which date from the 1970s, are books by David Noble and Edwin Layton. Noble, D.F., "America by Design: Science, Technology and the Rise of Corporate Capitalism," Oxford University Press, 1977. Layton, E.F. Jr., The Revolt of the Engineers; Social Responsibility and the American Engineering Profession," Press of Case Western Reserve University, Cleveland, 1971.

[15] SESTAT contains data from three national sample surveys of scientists and engineers. For further information, see N. Kannankutty and R.K. Wilkinson, "SESTAT: A Tool for Studying Scientists and Engineers in the United States" (Arlington, VA: National Science Foundation, Division of Science Resources Statistics, NSF 99-337, 1999).

[16] Engineers in the United States: An Overview of the Profession, 2004. Engineering Workforce Project #2. Cambridge, MA: Abt Associates Inc.

[17] Ibid. pp. xviii–xix.

[18] Ibid. p. xxi.

[19] LeBold, W.K., L. Burton, and L. Parker, "The Engineering Career At the End of the Century," paper presented at the 10th Biennial IEEE-USA Careers Conference Proceedings, 1998.

[20] Parker, Linda E., E-mail to Robert P. Morgan, July 7, 2006.

[21] Ibid.

[22] Commission on Professionals in Science and Technology, "The Outlook in 2003 for Information Technology Workers in the USA," August 28, 2003. Available online at: *www.cpst.org*.

[23] Commission on Professionals in Science and Technology, "IT Workforce Data Project Report Highlights," available online at: *http://www.cpst.org/ITWF_Highlight.htm*.

[24] Commission on Professionals in Science and Technology, "Twenty Years of Scientific and Technical Employment," STEM Workforce Data Report No. 1, June 4, 2004, available online at *www.cpst.org*.

[25] Ibid., p. 8.

[26] Ibid., Exhibits 2 and 3.

[27] Commission on Professionals in Science and Technology, "Scientific and Engineering Employment Grows Faster Than Total Labor Force Over Last Two Decades," June 1, 2004.

[28] Lowell, B.L., and M. Regets, "A Half-Century Snapshot of the STEM Workforce, 1950 to 2000," White Paper No. 1. Prepared for the STEM Workforce Data Project, Commission on Professionals in Science and Technology, August 2006.

[29] Ibid., Abstract.

[30] Ibid., Exhibit 2.

[31] Ibid., Exhibit 3.

[32] Ibid., Exhibit 4.

[33] Ibid., Exhibit 5.

[34] Ibid., Appendix 9.

[35] National Science Board, "Science and Engineering Indicators 2006," Appendices. Figures 3.5 and 3.6.

[36] I am grateful to Mark Regets of the National Science Foundation for a helpful discussion of these data.

[37] For some historical perspective on the issue of where allegiances of engineers lie, see Noble, D.F., "America by Design: Science, Technology and the Rise of Corporate Capitalism," Oxford University Press, 1977.

[38] I did not come across statistics which indicate the percentage of engineers that belong to professional societies and how that has varied with time. The statement about the declining membership and the reasons for it is taken from conversations with two knowledgeable sources.

[39] Gibbons, M., "Trends Over Time," ASEE PRISM, September 2005, pp. 22–23.

[40] Gibbons, M., "The Year in Numbers," available on ASEE website: *www.asee.org*. Viewed on September 10, 2006.

[41] Foreign nationals includes students here on both temporary and permanent visas. Source E-mail from Michael Gibbons to Robert P. Morgan, Sept. 12, 2006.

[42] The National Science Foundation tracks doctoral degrees awarded through a Survey of Earned Doctorates. Their results indicate that the percentage of engineering doctoral degrees awarded to permanent or temporary residents in 2004 was 61%. See "Doctorate Recipients from United States Universities: Summary Report," National Science Foundation, 2004.

[43] Available online at: *http://engtrends.com/degrees*.

[44] Heckel, Richard, Telephone conversation with Robert P. Morgan, August 12, 2006.

[45] For a recent detailed comparison of ASEE, EWC, and NSF data, see "Unraveling the Apparent Inconsistencies Between Various Sources of US Engineering Degree Data—Comparison of ASEE, EWC and NSF Surveys," Engineering Trends, August 2006. Available online at: *www.engtrends.com*.

[46] Available online at: *http://engtrends.com/degrees1945-001.php*.

[47] Heckel, Richard, Telephone conversation with Robert P. Morgan, August 12, 2006.

[48] "2001–2002 Recruiting Trends," College Employment Research Institute of Michigan State University. See also "Engineering Degrees Rising and Demand Falling—A Forthcoming Crisis? And What Will be the Impact on Enrollment? Report 0502C, Engineering Trends Research Studies. Available online at: *http://www.engtrends.com/IEE/0502C.php*.

[49] Sharma, S., and J. Green, "GM Tames Gas Guzzling With $11, 486-a-Year Engineers in India," Bloomberg News, Sept. 20, 2005.

[50] Heckel, Richard, Telephone conversation with Robert P. Morgan, August 12, 2006.

[51] Heckel, R., "Historical Trends and Near-Term Predictions of Statistics on Degrees, Enrollments and Research Expenditures for Engineering Education in the United States," Paper presented at Korean-American Scientists and Engineers Association Conference, August 2006. Available online at: *www.engtrends.com*.

[52] Inside Higher Education, "The graduate student population in the years ahead is likely to increase in size—and to have many more Asian engineers," August 9, 2006. Available online at: *http://www.insidehighered.com/news/2006/08/09/intl*.

[53] Ibid.

[54] Ibid.

[55] Jones, R.C., and B.S. Oberst, "Are Current Engineering Graduates Being Treated as Commodities by Employers?," Eur. J. Eng. Ed., 2003, Vol. 28, No. 3, 395–402.

[56] Ibid, p. 395.

[57] Ibid. p. 397.

[58] Ibid.

[59] Sperling, E., "What's Worrying Engineers?," Electronic News, April 6, 2006.

[60] Ibid.

[61] "Keeping U.S. Leadership in Engineering," ASEE International Engineering Education Digest, June 2006.

[62] I am grateful to Nirmala Kannankutty for her assistance with the SESTAT job satisfaction data.

[63] Bokorney, J., "Survey Show Industry is Stabilizing," EE-Evaluation Engineering, April 2005.

[64] Ibid, pp. 2 and 7 of 8.

[65] Bokorney, J., "Engineers Optimistic About industry Comeback," EE–Evaluation Engineering, April 2006 Feature Article.

[66] Bellinger, R., "Engineering is Still a "Fun" Thing to Do for Most," EE Times, August 25, 2004.
Snyder, J., "Salaries are Climbing, but Long Hours, Outsourcing, and a slew of Contract Jobs Continue to Fuel Job Security Anxiety," 2006 InfoWorld Compensation Survey, InfoWorld, June 12, 2006.

See also 2005 InfoWorld Compensation Survey, June 13, 2005.

Costlow, Terry, "Will This Recession Ever End?", Design News, May 17, 2004.

Sperling, Ed, "What's Worrying Engineers?", Electronic News, April 6, 2006.

Schnepf, Ken, 2006 Salary Survey: Does Your Job Provide You With the Right Chemistry?, ChemicalProcessing.com, undated. "While the majority of survey respondents told us that they are content with their salaries, benefits and job fulfillment, job satisfaction has declined and the biggest complaints are lack of recognition, followed by negative public opinion of the industry."

[67] I simply note that the elements that seem to arise most often in materials I have reviewed that seem to determine job satisfaction are the bread and butter concerns of salary and job security. I can't recall coming across anything about enjoying what one does. Perhaps it is embedded in "work/life issues." Or perhaps it's a sign of the times.

[68] Commission on Professionals in Science and Technology, "Science and Technology Salaries: Trends and Details, 1995-2005," STEM Workforce Data Project: Report No. 5, August 2006.

[69] Commission on Professionals in Science and Technology, "Trends in the Salaries of STEM Workers Mirror Those of the Entire U.S. Labor Force," Press Release, August 11, 2006.

[70] STEM Workforce Data Project Report No. 5, p.4.

[71] Ibid., Exhibit 1.

[72] Ibid. p. 1.

[73] Ibid., Exhibit 1.

[74] Ibid. p. 4.

[75] Langbein, L., "2004 IEEE-USA Unemployment Survey Results (11/29/04).

[76] Ibid. p.9.

[77] Ibid. p. 10.

[78] Harrison, R., "Employment Data Paints Disturbing Picture," in IEEE-USA's Today's Engineer Online, September 2005.

[79] Jones, D., "Are You Proud of Your Job?" USATODAY.com, May 23, 2005.

[80] "Students: The Top Ten Benefits of an Engineering Career," American Society for Engineering Education, 2004. The list is taken from the book "Studying Engineering" by R. Landis, Discovery Books, 1995.

[81] Kingsbury, A., "Wanted: Tech Talent," in U.S. News Report: America's Best Graduate Schools 2007, (2006).

[82] Finn, M.G., "Stay Rates of Foreign Doctorate Recipients from U.S. Universities, 2003," prepared for the National Science Foundation by the Oak Ridge Institute for Science and Engineering, November 2005.

[83] Ibid., Table 6.

[84] Ibid., p. 10.

[85] U.S. Government Accountability Office, "Off-shoring of Services: An Overview of the Issues," Report GAO-06-5, November, 2005; "Off-Shoring: An Elusive Phenomenon," A Report of the Panel of the National Academy of Public Administration for the U.S. Congress and the Bureau of Economic Analysis,

January, 2006; Sturgeon, T.J., et al., “Services Offshoring Working Group: Final Report,” Industrial Performance Center, MIT, September 10, 2006.

[86] Ernst, D., Complexity and Internationalization of Innovation—Why is Chip Design Moving to Asia?, op. cit.

[87] Morgan, R. P., “Global Outsourcing of Engineering Jobs,” op. cit.

[88] The Bent of Tau Beta Pi, Summer 2005.

[89] Florman, S.C., “How Engineers Can Fight Back,” May 19, 2004. Available online at: *www.technologyreview.com/articles/print_version/wo_florman051904.asp*.

[90] Begley, S., “As We Lose Engineers, Who Will Take Us Into the Future?”[90] *Wall Street Journal*, June 7, 2002.

[91] Begley, S., “Angry Engineers Blame Shortage on Low Pay, Layoffs and Age Bias,” *Wall Street Journal*, July 5, 2002.

[92] Florman, S.C., “How Engineers Can Fight Back,” op cit.

[93] Ibid., p. 2.

[94] Ibid., p. 3.

[95] Ibid.

[96] Florman, S.C., “My Profession and My Nation: A Worrisome Confrontation,” op. cit.

[97] Ibid., p. 16.

[98] Available online at: *www.technologyreview.com/forums/forum.asp?forumid=687&iPage=1*.

[99] Ibid.

[100] “A Red Flag In The Brain Game: America's dismal showing in a contest of college programmers highlights how China, India, and Eastern Europe are closing the tech talent gap,” Business Week, May 1, 2006.

[101] Johnson, R., in “Readers Report: The Future of Engineering: At home and Abroad,” Business Week, May 29, 2006, p. 19.

[102] Hira, R., and A. Hira, “Outsourcing America,” op. cit., Chapter 7.

[103] Ibid., p. 129.

[104] Yung, K., “Job Security Hopes Fading,” Dallas Morning News, June 26, 2004.

[105] Hira and Hira, op. cit., p. 130.

[106] Ibid., pp. 131–134.

[107] Ibid., pp. 134–135.

[108] Ibid., pp. 136–139. For a discussion of the impact of offshoring on real estate markets, see Barghan, A.D., and C. Kroll, “The New Wave of Outsourcing,” Paper 1103, Fisher Center for Real Estate and Urban Economics, Univ. Of California, Berkeley, 2003.

[109] Ibid., pp. 140–142.

[110] Waldman, A., “Indians Go Home, but Don’t Leave U.S. Behind,” *New York Times*, July 24, 2004.

[111] Hira and Hira, op.cit., pp.142–143.

[112] Online at: *http:www.techsunite.org/offshore/*. July 25, 2006. Information unchanged as of September 18, 2006.

[113] Bronfenbrenner, K., and S. Luce, "The Changing Nature of Corporate Global Restructuring: The Impact of Production Shifts on Jobs in the U.S., China, and Around the Globe," paper submitted to the US-China Economic Security and Review Commission, October 14, 2004.

[114] Ibid. Executive summary.

[115] Ibid.

[116] Ibid.

[117] Ibid.

[118] "Does the MLS Program Collect Information on Offshoring and Outsourcing?" Bureau of Labor Statistic Fact Sheet. (on-line).

[119] Brown, S.P., "Mass Layoff Statistics Data in the United States and Domestic and Overseas Relocation," Presented at the EU-US Seminar on "Offshoring of Services in ICT and Related Services," Brussels, Belgium, December 13–14, 2004.

[120] Ibid. p. 7.

[121] Ibid, p. 8.

[122] Ibid.

[123] The Bridge, Vol. 35, No. 3, National Academy of Engineering, Fall 2005.

[124] Kenney, M., and R. Dossani, "Offshoring and the Future of Engineering: An Overview," The Bridge, Vol. 35, No 3. Fall, 2005, pp. 5–12.

[125] Ibid, pp. 5-6.

[126] Ibid p. 6.

[127] McKinsey Global Institute. 2005. "The Emerging Global Labor Market: Part I—The Demand for Offshore Talent in Services," Washington, D.C.

[128] Kenney and Dossani, op. cit., p. 6.

[129] Ibid.

[130] Ibid, p. 7.

[131] Ibid, pp. 7–8.

[132] Ibid, p. 9.

[133] Ibid, p. 10.

[134] Ibid, pp. 10–11.

[135] Ibid, p. 11.

[136] Hira, R., "Impact and Trends of Offshoring of Engineering Tasks and Jobs," The Bridge, Vol. 35, No. 3. Fall 2005, pp. 22–27.

[137] Hira, R., and A. Hira, "Outsourcing America: What's Behind the National Crisis and How We Can Reclaim American Jobs," American Management Association, 2005.

[138] Hira, R., "The Bridge," 2005. Op. cit., p. 22.

[139] Ibid, p.23.

[140] BLS (Bureau of Labor Statistics). 2004. Displaced Workers Survey. Washington, D.C.: U.S. Department of Labor.

[141] Hira, R., The Bridge, 2005.Op. cit, p. 23.

[142] Hira, Ron, E-mail to Robert P. Morgan, July 26, 2006.

[143] Hira, R., The Bridge, 2005.Op. cit, p. 24.

[144] Ibid, p. 24.

[145] Ibid.

[146] Ibid. p. 26.

[147] Ibid.

[148] Ibid, p. 27.

[149] Ibid.

[150] Wulf, W.A., "A Disturbing Mosaic," The Bridge, Vol. 35, No. 3, National Academy of Engineering, Fall, 2005. pp.28–32.

[151] Ibid. pp. 30–31.

[152] Ibid, pp. 31–32.

[153] Ibid, p. 32.

[154] "Framing the Outsourcing Debate: Placing the United States on a Level Playing Field with China and India," Master of Engineering Management Program, Duke University, December 2005.

[155] Ibid. p. 2.

[156] His most recent effort is "Engineering Gap? Fact or Fiction. It's no time to panic about the numbers of engineers India and China are graduating compared with the U.S. Here's the real story in this big debate," Business Week Online, July 10, 2006.

[157] Testimony Of Vivek Wadhwa To The U.S. House Of Representatives Committee On Education And The Workforce, May 16, 2006.

[158] Ibid.

[159] "Duke University Engineering Offshoring Questionanaire."

[160] Ibid.

[161] E-mails from Vivek Wadhwa to Robert P. Morgan, June 21, 2006

[162] "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," National Academy Press, 2006.

[163] "Framing the Outsourcing Debate," p.6.

[164]Freeman, R., "Does Globalization of the Scientific/Engineering Workforce Threaten US Economic Leadership?" April 2005. Available online at: *http://www.nber.org/~confer/2005/IPEs05/IPEs05program.html*. See also PowerPoint slide from his presentation "Globalization of Innovation: Workforce Implications" at NAS STEP Workshop, April 21, 2006.

[165] Jensen, J. B., and L. G. Kletzer, “Tradable Services: Understanding the Scope and Impact of Services Offshoring,” July 14, 2005 revised. Forthcoming in Brookings Trade Forum 2005: Offshoring White-Collar Work—The Issues and the Implications,” L. Brainard and S.M. Collins, editors.

[166] “Framing the Outsourcing Debate,” p. 4.

[167] Ibid, pp. 3-4.

[168] Ibid, p. 10.

[169] Mr. Leonard is an economic consultant for the Manufacturers Alliance. American Sentinel University offers on-line information technology degrees.

[170] Leonard, J., “Offshoring of Information Technology Jobs: Myths and Reality.” Prepared for American Sentinel University, May 2006. p. 2.

[171] Shaw, R., “How the defenders of IT offshoring think,” June 4, 2006.

[172] Barlas, D., “Offshore’s IT Impact,” Line 56—the E-Business Executive Daily, June 5, 2006.

[173] Hira, Ron, E-mail to Robert P. Morgan, July 28, 2006.

[174] Available online at: *http://www.ibm.com/news/in/en/2006/06/20060612_ibm_chariman_ceo.html*.

[175] Mann, C., “New Engineering Occupations: IT a Microcosm for All Engineers,” PowerPoint slide in Mann, C.L., “Prospects for US Manufacturing and Engineering in the Global Economy,” 2006 MIT Manufacturing Summit, April 27–28, 2006.

[176] Hira, R., and A. Hira, “Outsourcing America: What’s Behind the National Crisis and How We Can Reclaim American Jobs,” American Management Association, 2005, p. 179.

[177] Florida, R., “The Flight of the Creative Class: The New Global Contribution for Talent,” Harper Business, 2005.

[178] Ibid, p. 97.

[179] Ibid. pp. 98–102.

[180] Saxenian, A., “Silicon Valley’s New Immigrant Entrepreneurs,” San Francisco: Public Policy institute of California, 1999.

[181] Florida, R., op. cit., pp. 107–108.

[182] Ibid. p. 71.

[183] Morgan, R. P., “Science and Technology for International Development: An Assessment of U. S. Policies and Programs, Westview Press, 1984.

[184] Arora, A., and A. Athreye, “The Software Industry and India's Economic Development,” Information Economics and Policy, April 2001.

[185] “IMMIGRATION: USA Today: Indian entrepreneurs increasingly go home to join tech-industry explosion.” August 22, 2006. Available online at: *http://www.usatoday.com/tech/columnist/kevinmaney/2006-08-22-indian-enterpreneurs_x.htm*.

[186] Samuelson, P., Journal of Economic Perspectives, 2004.

[187] Baumol, W., and R. Gomory, “Global Trade and Conflicting National Interests,” 2004.

[188] My own interest is science and technology for development began with my involvement in Volunteers for International Technical Assistance (VITA) about 45 years ago.

[189] Online at: *http://www.nasscom.in/Nasscom/templates/LandingPage.aspx?id=5345*.

[190] "Globalization of Engineering Services—The next frontier for India," available online at: *http://www.nasscom.in/Nasscom/templates/NormalPage.aspx?id=49790*.

[191] Online at: *http://www.nasscom.in/Nasscom/templates/NormalPage.aspx?id=49790*.

[192] Ibid. pp. 2–3.

[193] Ibid. p. 4. The summary doesn't not break out a percentage for engineering services outsourcing alone.

[194] Ibid. p. 4.

[195] Ibid. pp. 4–5. "First-time right" designs by Indian ESO partners in this case went from the 45 to 55% of all designs in 2001 to 89 to 92% in 2004. The latter range met or exceeded the levels for the client firm's own engineers.

[196] Ibid. pp. 5–6.

[197] Ibid. pp. 6–7.

[198]Ibid. p. 7.

[199] Ibid. p. 8.

[200] Ibid. pp. 8–11.

[201] Ibid. p. 13.

[202] Ibid.

[203] In describing the NASSCOM-BAH report, I have taken the point of view that the words 'outsourcing' and 'offshoring' are used interchangeably to mean the same thing. Thus, I have substituted offshoring for outsourcing in describing this report to be consistent with the rest of my paper.

[204] Ernst, D., "Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks," East-West Center Special Report No. 10, July 2006. Honolulu, Hawaii.

[205] Ernst, D., "Outsourcing Lacks Reliable Statistics for Policymaking," East-West Center, April 7, 2004. Available online at: *www.eastwestcenter.org/events-en-detail.asp?news_ID=215*.

[206] Ernst, D., "Innovation Offshoring," op. cit., pp. 2, 28.

[207] Ibid. pp. 29–30.

[208] Ibid. 30–35.

[209] Norman, D., "The Invisible Computer," MIT Press, Cambridge, MA, 1998.

[210] Lester, R.K., and M.J. Piore, "Innovation: The Missing Dimension," Harvard U. Press, 2004.

[211] Ernst, "Innovation Offshoring", op. cit., p. 35.

[212] Ibid.

[213] Ibid. pp. 1, 36.

[214] Ibid. p. 36.

[215] Ernst, D., Complexity and Internationalization of Innovation—Why is Chip Design Moving to Asia?, International Journal of Innovation Management, Vol. , No 1., March, 2005. Also published on *www.gabeoneda.com*.

[216] Ibid. p. 1. Two primary references are Pavitt, K., 1999, Technology, Management and Systems of Innovation, Edward Elgar, Cheltenham; and Patel, P., and K. Pavitt, 1991, "Large Firms in the Production of the World's Technology: An Important Case of Non-globalisation," Journal of International Business Studies, 22(1): 1–21.

[217] Ernst, D., "Complexity and Internationalization of Innovation," op. cit., p. 1.

[218] Ibid. p. 2.

[219] Ibid. p. 15.

[220] Ibid.

[221] Ibid. p. 16.

[222] Freeman, R.B., "Does Globalization of the Scientific/Engineering Workforce Threaten U.S. Economic Leadership?" Working Paper 11457, National Bureau of Economic Research, Cambridge, MA, June, 2005. © 2005 by Richard B. Freeman.

[223] Ibid. Abstract.

[224] Ibid, p. 27.

[225] Dorgan, B.L.. "Take This Job and Ship It: How Corporate Greed and Brain Dead Politics are Selling Out America," Thomas Dunne Books/St. Martin's Press, New York, 2006.

[226] Ibid., p. 201.

[227] For a further critique of *The World is Flat*, see the review by J. Faux of the Economic Policy Institute rntitled "Flat Note From the Pied Piper of Globalization," Dissent, Fall 2005, pp. 64–67.

[228] Dorgan, op. cit., p. 230.

[229] Ibid., p. 232.

[230] Ibid., p. 23.

[231] Krugman, P., "Progress or Regress?" *New York Times*, Sept. 15, 2006. "The Non-Working Man's Burden, Editorial, *New York Times*, August 8, 2006.

[232] "Mr. Bush and Labor Day**:** Workers aren't benefiting from growth", *Washington Post* Editorial, Monday, September 4, 2006; A18

[233] This is based upon a Working Abroad survey which does not provide information about the nature of the employment (e.g., temporary or for a U.S. or overseas firm).

[234] CNN Money, February 13, 2006.

[235] Chen, John, E-mail to Robert P. Morgan. June 7, 2006.

[236] Ibid.

[237] Rosenzweig, M., "Where are Chemical Engineers Headed?" Chemical Processing, August, 2004.

[238] Ibid.

[239] McLeod, Kenneth, E-mail to Robert P. Morgan, June 20, 2006.

[240] Arthurs, Eugene, E-mail to Robert P. Morgan, July 30, 2006.

[241] Arthurs, Eugene, E-mails to Robert P. Morgan, July 30 and 31, 2006.

[242] "Deere To Expand Operations In Pune, India", News Release, Deere & Company, January 7, 2005.

[243] Wonscott, P., “IBM To Triple Its Investment in India. Country’s Appeal Evolving Beyond Inexpensive Labor,” *Wall Street Journal*, June 7, 2006, Page D10.

[244] Waters, R., “EDS To Move More Jobs to Low-Cost Locations,” *Financial Times*, August 2, 2006.

[245] I find the EDS story interesting. This is the company that was founded by Ross Perot (who has since left), who, when he ran for president, was a staunch opponent of the offshoring that the company is heavily involved in now.

[246] McDougall, P., “CSC to Cut 1,800 Domestic Jobs, Add 2,000 Offshore Workers,” Information Week, August 9, 2006.

[247] “Cashing Their Chips,” Editorial, *New York Times*, Sept. 8, 2006.

[248] Freeman, S., “Ford's Plans Shrink Along With Its Workforce,” *Washington Post*, Sept.16, 2006; D01.

[249] Hart, K., “Smaller Firms Buy Overseas Shops: WebMethods Follows Trend,” *Washington Post*, September 18, 2006, D01.

[250] Kenney, Martin, E-mails to Robert P. Morgan, July 31 and August 1, 2006.

[251] Sturgeon, T.J., et al., “Services Offshoring Working Group: Final Report,” Industrial Performance Center, MIT, September 10, 2006.