Implications of Information Technology for Employment, Skills, and Wages: Findings from Sectoral and Case Study Research

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April 2004

SRI International

• April 2004

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Final Report

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SRI Project Number P10168

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This literature review was prepared by Michael J. Handel of the University of Wisconsin–Madison and the Levy Economics Institute, as a consultant to the Science and Technology Policy Program of SRI International, Arlington, Virginia.

Funding was provided by the National Science Foundation. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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ACKNOWLEDGMENTS

This publication was prepared by Michael J. Handel of the University of Wisconsin at Madison and the Levy Economics Institute under contract with SRI International. Funding was provided by the National Science Foundation.

Expert technical reviewers supplied important feedback on the draft manuscript, and their suggestions strengthened it considerably. These individuals include Paul S. Adler, University of Southern California; Eileen L. Collins, Center for Women & Work, Rutgers University; and Kenneth I. Spenner, Duke University.

Valuable contributions and insights came from Lori Thurgood of SRI International, who was also responsible for the technical editing and preparation of the final manuscript for publication.

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CHAPTER 1: INTRODUCTION

A previous review examined conceptual issues, historical information, and econometric evidence regarding the impact of information technology (IT) on employment, skills, and wages (see Handel 2003). This review examines evidence from industry-specific and case studies for the light they shed on key issues raised in the previous paper, i.e., the extent to which IT eliminates jobs, raises job skill requirements, and, consequently, contributes to increased wage inequality between less- and more-skilled workers. The concern is particularly relevant for the last twenty years, during which wage inequality rose dramatically, especially in the 1980s. As reviewed in Handel (2003), many economists believe that computers and information technology have increased the demand for human capital, an idea known as skill-biased technological change. Sectoral and case study evidence are particularly valuable because they tend to give a much more concrete idea of how specific technologies affect jobs in particular contexts.

As discussed in Handel (2003), computers might increase job skill demands and inequality through different means:

1. IT may raise skill requirements by altering the task content of existing jobs because:
    - A. the equipment and software are difficult to learn;
    - B. the character of work changes from manual or routine to a more conceptual or abstract set of tasks;
    - C. information becomes decentralized, which encourages firms to restructure work roles to require that front-line workers use this information as part of taking on more decision-making and problem-solving responsibilities formerly reserved for more-skilled workers.

2. IT may raise overall skill requirements by shifting the distribution of workers between occupations, increasing the relative numbers in high-skilled occupations, even if the content of most jobs remains relatively unchanged. This may occur because:
   A. IT requires a greater number of skilled workers to manage the technology itself (e.g., programmers, technicians, maintenance workers) or to analyze the information it generates (e.g., accountants, market researchers);
   B. IT reduces the number of less-skilled workers by automating some positions out of existence (e.g., data entry clerks, telephone operators).

3. IT may alter the distribution of jobs across industries in the direction of those that are relatively more skill intensive (e.g., reducing manufacturing employment and increasing high-end service employment), even if it does not alter the nature of work or the distribution of workers across occupations within industries (Attewell 1987).

Although the preceding presents changes in job content and changes in the occupational and industrial distributions of employment as distinct, any actual case may involve some combination of them. Nevertheless, this is a useful analytical framework for organizing the evidence and understanding the kinds of forces that may be at work as a result of the expansion of IT in the workplace.

As described below, there are other researchers in the deskilling tradition who believe that the use of IT tends to lower the skill requirements of most jobs (e.g., Braverman 1974), though strong versions of this thesis have much less currency today than previously.

More common is the view that computers and automation are better able to substitute for less-skilled tasks, such as physical work or routine paperwork processing, rather than more-skilled tasks involving decision making and judgment. In addition, automated manufacturing equipment has long been viewed as requiring a greater number of maintenance workers (Woodward 1965), a view confirmed by studies cited in the previous review (e.g., Fernandez 2001), as well as some described below. Both tendencies would increase skill requirements through changes in the occupational distribution.

In addition, many argue that computers in both office and factory settings require less-skilled workers to have more skills and accept greater responsibility. Computer-based tasks are more varied, abstract, complex, and information intensive. Processes are more integrated and interdependent. In manufacturing this means processes are less segmented and operators need a deeper understanding of the whole production system rather than just one area. In certain kinds of office work, lower-level clerical workers have responsibility for updating corporate-wide databases in which any incorrect information will be propagated instantaneously throughout the system without the previous safeguard of another worker checking its accuracy. This requires greater attention to detail from workers entering information into the system. Computer systems also change more rapidly than traditional equipment and require greater flexibility and willingness to learn, often in classroom settings rather than informally on the job (Zuboff 1988; Hirschhorn 1984; Pullman and Szymanski 1986, pp.124f.,152; Fearfull 1992, pp.433f.; Hirschhorn and Mokray 1992, pp.17,20ff.; Attewell 1992, pp.56,70,74; OTA 1986, p.341).

Most of the results reviewed here do not support the deskilling view, but the question is whether the skill upgrading view exaggerates the magnitude of the changes claimed when the actual impact is more modest (cf. Spenner 1988). Computer training data are relatively scarce, but there is the example of Internal Revenue Service agents who, in 1986, were issued laptops loaded with specialized software for audits and general word processing, spreadsheet, database, and communications software. They received seven days of classroom training and five weeks of on-the-job training, in which instructors accompanied or consulted with trainees and organized workshops (Pentland 1994, pp.374f.). The relatively modest level of training required for these novice users does suggest that the introduction of computers upgraded skill demands greatly, and it is highly likely that most of the computer fundamentals included in the training program can now be taken for granted for more recent cohorts entering the work force.

Following most of the case study literature, this review focuses on the impact of IT on manufacturing and non-managerial, non-professional office workers. The section on manufacturing concentrates on the impacts of two technologies, (1) numerically controlled and computer numerically controlled machines and (2) industrial robots, after considering some other technologies more briefly. The section on lower-level office work focuses on the impacts of computers in banking and insurance and users of computer-aided design systems, in addition to considering some other work situations more briefly. Throughout this review the focus is on results that have implications for employment levels, skill demands, and wages, rather than other issues such as job satisfaction or organizational changes, except insofar as the latter has relevance for the first set of questions.

CHAPTER 2: MANUFACTURING AUTOMATION

General

Automation is a term coined after World War II in the auto industry to describe the use of automatic devices and controls on mechanized production lines. As currently understood, automation is more than the simple substitution of mechanical action for human labor. Automated equipment is at least partly governed by a programmable control unit and sensors that feed back real-time progress information to the control unit or to a control panel monitored by humans who can take corrective action if necessary. If the control unit and sensors are integrated into a self-regulating system and do not require human intervention beyond initial set-up, like a private home's furnace and thermostat, it is a closed-loop system. If sensors provide feedback to human operators who must make important decisions and choices, rather than conveying directly to the control unit as a basis for automatic action, it is an open-loop system.

For both the general public and manufacturing management and engineers, a common vision is that of the completely automated process. Since the 1950s automation enthusiasts have proclaimed the coming era of the fully automatic, "unmanned," or, more recently, "lights-out" factory. The concept of computer-integrated manufacturing (CIM) extends the concept beyond the factory to the integration of automation at all stages of the production process from electronic customer ordering to computerized planning, scheduling, and execution of all manufacturing operations to the updating of all company databases (Flamm 1988, p.271).

However, the reality of manufacturing automation has almost always fallen far short of this ideal. Machine unreliability and restrictions on the ability of human operators to intervene in cases of unforeseen problems has led to some significant failures. The integration of manufacturing processes under complete computer control has also been limited by the difficulty of understanding, documenting, modeling, and programming processes of previously unrecognized complexity. The lack of standardization across vendors has often made it difficult for machines and software to interface with one another and inhibited integration beyond "islands of automation" (Clark 1995, pp.73,77; Giertz 1987, p.8).

Even today the degree to which automation, at any level of sophistication, is responsible for job losses, stunted job growth, or downward pressure on wages for less-skilled workers is still poorly understood. One brief review of case studies by the U.S. Department of Labor's Bureau of Labor Statistics concluded that relatively few people have been laid off directly due to technological change because investment usually occurs during periods of economic expansion and overall job growth. In addition, most new technology diffuses relatively gradually and most firms prefer to retrain and reassign workers if possible (Mark 1987, p.27f.).

More formally, the U.S. General Accounting Office surveyed 400 establishments in 1986 to understand the reasons for plant closures and permanent layoffs. The most frequent of 14 reasons mentioned were lower product demand (70%), increased competition (69%), and high labor costs (57%), while plant obsolescence (23%) and automation (16%) were ranked tenth and twelfth, respectively (cited in Cyert and Mowery 1987, p.60f.).

Similarly, a national survey of over 1,500 union and management negotiators asked which of seventeen factors most heavily influenced negotiations in 1993-1996 contract talks. Adjustments to new technology and pressure to upgrade skills ranked near the bottom in the judgment of both groups. Less than 5 percent ranked those considerations as "heavily influencing" negotiations (Cutcher-Gershenfeld, Kochan, and Wells 1998, p.25.).

Indeed, one needs to be cautious not to overestimate the employment effects of IT developments in the last twenty years compared to more traditional mechanization and rationalization that has been occurring for a long time. For example, it was cargo containerization introduced in the 1960s, not the more recent use of computerized cargo tracking, that was mostly responsible for the fall in the number of longshoremen working in New York Harbor from 27,000 in the early 1960s to 2,700 today (Smothers 2000; Eaton 2001). Likewise, improvements in plastic packaging in the 1970s permitted more meat processing tasks to be performed by less-skilled line workers in slaughterhouses rather than skilled meat cutters in supermarkets, putting pressure on the latter's wages and employment (Walsh 1993, pp.77ff.). The effects of technological innovation on work and employment are nothing new to the computer age.

One case illustrating the difficulties of full automation is Clark's (1995) study of Pirelli's decision to build a state-of-the-art plant for manufacturing wiring cable in Wales, UK in the late 1980s. He began by noting, "In the early and mid-1980s, the holy grail of technical innovation was full computer control of all aspects of production and its correlate, the 'workerless factory'...This conception of CIM led to some enormous and costly mistakes" in general, including at the Pirelli plant (Clark 1995, p.72f.). Pirelli's corporate management was "totally committed to full automation and reducing the people element to a minimum," according to the project's manager (Clark 1995, p.84).

The CIM system was to handle all stages of the process from receiving orders to completing the finished product, including sequencing orders, just-in-time delivery of materials at each stage of the process using automated guided vehicles (AGV), set-up and control of all machine processes, inventory management, quality control, and a paperless accounting system to track product status and cost. Operators would monitor the process and troubleshoot problems (Clark 1995, pp.88f.).

However, the complexity of the system tripled its cost, and software bugs and machine breakdowns required greater operator intervention and more engineering and maintenance staff than planned. The plant opened in 1988 but did not achieve acceptable production levels until 1990, after it had reintroduced manual procedures and operator discretion, though subsequent improvement in the system successfully re-automated some of them eventually (Clark 1995, pp.97ff.,215ff.). Ironically, one of the biggest problems was programming the flexibility in product changes that is commonly thought to be the strength of such systems. The plant produced 600 kinds of cables; one systems engineer described the programming task to encompass this variety of products as "a nightmare" (Clark 1995, p.106).

In terms of employment levels and composition, this plant had 156 employees when finally running at capacity in 1990: 56 percent were operators, 12 percent maintenance, and 32 percent white collar (Clark 1995, p.140). In the absence of comparable figures from less automated sister plants, it is not clear how to evaluate these numbers, but automation in this factory clearly did not eliminate operators or blue-collar workers more generally.

Some limited idea of the skill requirements in this plant can be gathered from the fact that in the first year after the plant opened, employees received about three weeks of training total, which covered the nature of the products, safety, and the team-based production strategy, as well as the automated equipment. The plant also instituted a far more extensive long-term training system, but the case study is somewhat sketchy on its details (Clark 1995, pp.41ff.).

Some more systematic evidence on manufacturing automation can be found in the Survey of Manufacturing Technology (SMT) conducted by the Census Bureau in 1988 and 1993 for selected manufacturing industries in which certain forms of automation were thought to be most prevalent.[1] These industries accounted for 42.5 percent of total manufacturing employment and 7.8 percent of total employment (author's calculations, Current Population Survey, Outgoing Rotation Group file for 1993).

Columns 1 and 4 of Table 1 indicate that while computer-aided design and engineering (CAD/CAE)—an office technology described in the next section—was one of the most widely used advanced technology in both 1988 (reported by 39% of plants) and 1993 (reported by 59% of plants), its integration with the production process in the

[1] The industries and their 2-digit standard industrial codes were: fabricated metal products (34), industrial machinery (35), electronic/electrical equipment (36), transportation equipment (37), instruments and related products (38).

Table 1. Percentage of Establishments in Selected Manufacturing Industries (SIC 34-38) Reporting Use of Advanced Technology and Plans to Adopt Within Five Years (Survey of Manufacturing Technology, 1988 and 1993)

	1988			1993			Difference (1993-1988)	
	Actual	Planned	Projected	Actual	Planned	Projected	Actual – Actual	Actual – Projected
CAD/CAE	39.0	19.6	58.6	58.8	9.5	68.3	19.8	0.2
CAD/CAM	16.9	21.1	38.0	25.6	15.3	40.9	8.7	-12.4
NC/CNC	41.4	7.9	49.3	46.9	6.3	53.2	5.5	-2.4
Robots								
Pick & Place	7.7	12.2	19.9	8.6	8.5	17.1	0.9	-11.3
Other	5.7	11.2	16.9	4.8	7.5	12.3	-0.9	-12.1
PLC	32.1	10.7	42.8	30.4	8.6	39.0	-1.7	-12.4
FMS	10.7	11.5	22.2	12.7	9.7	22.4	2.0	-9.5
AGV	1.5	3.8	5.3	1.1	2.1	3.2	-0.4	-4.2
EDI	14.8	20.3	35.1	17.9	18.8	36.7	3.1	-17.2

Note: "Planned" refers to the percentage of the sample that had not adopted the technology but planned to do so in the following five years. "Projected" is the sum of percentages in the "Actual" and "Planned" columns and refers to the projected percentage of establishments using the technology in the following five years. The figures under "Actual – Actual" give the actual growth in usage between 1988 and 1993. The figures under "Actual – Projected" give the difference between actual level of usage in 1993 and the projected level for 1993 based on planned usage in 1988 given in Column 3.

Industries: Fabricated metal products (34), industrial machinery (35), electronic/electrical equipment (36), transportation equipment (37), instruments and related products (38)

CAD/CAE = computer-aided design/computer-aided engineering
CAD/CAM = computer-aided design/computer-aided manufacturing
NC /CNC = numerically controlled/computer numerically controlled machine tools
PLC = programmable logic controllers
FMS = flexible manufacturing cell or system
AGV = automated guided vehicle systems
EDI = electronic data interchange (inter-company computer networks linking plant to suppliers, customers, or suppliers)

Source: U.S. Department of Commerce 1989 (Table 2), 1994 (Table 2B) form of computer-aided manufacturing (CAD/CAM) systems was relatively uncommon. Even in 1993 less than 26 percent of the plants surveyed could convert computer blueprints into machine instructions and transmit those instructions to production equipment.

Numerically controlled (NC) and more recent computer numerically controlled machines (CNC), described further below, were the next most common technology, used by about 41 percent of plants in 1988 and 47 percent of plants in 1993.

The other technologies tended to be used at low levels and showed little growth over the five-year period. Programmable logic controllers (PLC), which are another device similar to a computer that controls industrial processes, were the most common of the remaining technologies. However, the number of plants using them remained constant at a little above 30 percent.

Only 13.4 percent of plants used any kind of robot in either year, and the percentage of users did not change over the five years despite the fascination that this form of automation has long attracted. Flexible manufacturing systems (FMS) are a more advanced form of automation that integrates two or more machines that automatically accept inputs and transfer outputs to one another. In a sense, FMS is a more developed building block of a fully automatic or computer-integrated manufacturing (CIM) system. However, only 11-13 percent of plants reported using FMS in either year. Likewise, automated guided vehicles (AGV) are an advanced form of automation: robotic carts that can carry materials and work in progress over longer distances in a plant. Use of AGVs was very rare. Fewer than 2 percent of plants used this very advanced form of automation in either year. Most plants, it seems, found it easier or cheaper to use human labor to load and unload parts from machines or transport them within the plant.

Finally, electronic data interchange (EDI) refers to computer networks that link plants and their suppliers and customers in order to facilitate information exchange regarding matters such as ordering, scheduling, billing, and inventory management. EDI is often said to be a critical component of a lean manufacturing strategy that allows plants to eliminate unnecessary buffer stocks of material inputs and the labor associated with them, as well as to require remaining workers to engage in more complex problem solving and trouble shooting to make sure that production continues to function without a cushion of slack resources. If EDI is a necessary or highly complementary feature of such skill-enriched jobs, the data suggest only limited penetration of this production paradigm in the late 1980s to early 1990s; only 15-18 percent of plants used EDI at that time. With developments in networking and the internet since 1993, this percentage has almost certainly increased significantly since the last SMT was administered.

Both waves of the SMT asked non-users if they planned to adopt each technology in the next five years. Column 2 of Table 1 gives the percentage of plants that reported in 1988 that they planned to adopt a technology by 1993. When added to the figures for current users, the projected percentages of users in 1993 (column 3) can be compared to the actual percentage of users in 1993 (column 4). Column 7 gives the actual change in advanced technology usage between 1988 and 1993, and Column 8 gives the difference between actual use in 1993 and projected use in 1993 based on stated intentions to adopt given in 1988.

While the projection for stand-alone CAD/CAE systems and NC/CNC machines proved surprisingly accurate, projected usage rates for 1993 were overly optimistic by over 10 percentage points for most of the other technologies (column 8). For most of the advanced technologies, the percentage of users barely changed (column 7). This is one reason to be cautious about any projections of future technology use, including similar responses from the 1993 survey regarding plans for adoption by 1998 (columns 5 and 6). Unfortunately, the SMT program was discontinued so there is not another wave against which the 1993 projections can be compared.

The data in Table 1 are limited by the fact that there is no information on the extent of usage other than simple presence or absence within a plant. The published reports indicate strong positive associations between technology use, on the one hand, and total plant employment and value of output, on the other. If larger plants accounting for a disproportionate share of total output also account for a disproportionate share of technology adoption, it is quite possible that the figures in Table 1 understate the true impact of automation on employment.

The SMT 1993 provides some additional information bearing on this question for 1993. The survey asked respondents to give the number of dedicated workstations or pieces of equipment for certain discrete technologies, reported in Table 2. Since CAD/CAE programs can run on general purpose computers, the interpretation of this figure is problematic, but the much fewer numbers of integrated CAD/CAM systems is consistent with the results in Table 1.

Table 2. Number of Dedicated Work Stations or Pieces of Equipment in Selected Manufacturing Industries (SIC 34-38) (Survey of Manufacturing Technology, 1993)

Technology	Number of Units
CAD/CAE	179,466
CAD/CAM	38,047
NC/CNC	171,772
Robots	
Pick and Place	31,512
Other	20,706
PLC	214,378

Industries: Fabricated metal products (34), industrial machinery (35), electronic/electrical equipment (36), transportation equipment (37), instruments and related products (38)

CAD/CAE = computer-aided design/computer-aided engineering
CAD/CAM = computer-aided design/computer-aided manufacturing
NC/CNC = numerically controlled/computer numerically controlled machine tools
PLC = programmable logic controllers

Source: U.S. Department of Commerce 1994 (Tables 5A, 5C, 6C, 6G, 6I, 9G)

More interestingly, the survey found that there were about 172,000 NC/CNC machines in use in 1993. Some, though not all, employers had machinists and operators work on two NC/CNC machines rather than a single machine, as was customary prior to automation (Shaiken 1984, pp.78,80,91). Assuming that all employers required their workers to double up on the machines and experienced no increase in demand as a result of adopting the new technologies (both unrealistic assumptions that skew estimates of displacement upward), the figures for NC/CNC usage imply reduced manpower needs on the order of 86,000 workers per shift or 172,000 assuming two shifts. However, the actual number might well be higher because NC/CNC machines are much faster and are often equipped with multiple tools, potentially reducing the total number of machine tools in a shop that need human operators (Watanabe 1987, p.173; Shaiken 1984, p.71). Some generally non-representative studies estimated that NC/CNC machine tools displace 2-3 workers, but other estimates are highly variable and much of the estimated labor savings no doubt depends on whether the plants that were studied produced standard parts in high volume or smaller batches of more customized parts (Kaplinsky 1987, p.86; Watanabe 1987, pp.61ff.).

The SMT also found 52,000 robots in use in 1993. As the discussion of industrial robots below indicates, most studies estimate that robots substitute for two workers, again assuming no increase in product demand, though there is also case study evidence that the displacement is far less than that. Assuming robots eliminate the need for two jobs, the robot population figure above implies 104,000 fewer jobs than otherwise or 276,000 jobs when combined with the NC/CNC figures assuming one job displaced per machine.

Total employment in 1993 was 120.3 million workers (*Economic Report of the President, 2004*, Table B-36). From this figure and tabulations from the Current Population Survey, one can calculate that for 1993 about 31.7 million Americans worked in what are usually considered blue-collar jobs (craft, operator, and laborer), of whom about 13.3 million worked in manufacturing and 5.3 million worked in the manufacturing industries covered by the SMT (author's calculations, Current Population Survey, Outgoing Rotation Group file for 1993). Using a job displacement figure due to robots and NC/CNC of 276,000, this implies that about 0.23 percent of all employment, 0.87 percent of all blue-collar employment, 2.1 percent of blue-collar manufacturing jobs, and 5.2 percent of blue-collar jobs in the SMT industries were either eliminated or failed to be created because of the use of robots and NC/CNC machines in 1993, relative to a situation in which none of those technologies were used but all other relevant conditions were held constant. Since this assumes no increase in product demand as a result of the increased productivity caused by the new equipment, these estimates could easily be overstated, though the omission of effects for FMS and perhaps some other advanced technologies biases the estimates downward.

Nevertheless, the estimates of displacement clearly represent a very small fraction of total employment and even total blue-collar employment. Assuming most of these displaced jobs are either not created or eliminated through attrition, rather than layoffs of mid-career workers, it seems likely that most people who might otherwise have filled these positions would have been able to find other, similar jobs without great difficulty. From these "back of the envelope" calculations, it does not appear that advanced manufacturing automation is responsible for significant loss of blue-collar job opportunities, though its effects in manufacturing in general and in specific manufacturing industries may be somewhat greater.

By comparison, total manufacturing employment in the United States as a percentage of total employment fell from 22.4 percent to 13.9 percent between 1983 and 2001, and the proportion of manufacturing workers in blue-collar occupations fell from 62.2 percent to 57.3 percent over the same period, implying that blue-collar manufacturing jobs as a share of total employment fell from 13.9 percent to 8.0 percent (author's calculations, Current Population Survey, Outgoing Rotation Group files). It is not possible to determine how much of the 5-percentage point drop in blue-collar workers within manufacturing or the 6-percentage point drop within the overall workforce is due to new computer-based technology, developments in traditional technologies that were similar to those occurring throughout manufacturing history, or the effects of trade and offshore production. However, these figures provide an upper bound on the effects of nearly twenty years of diffusion of IT-based manufacturing technology.

Table 3 reports key results from a special SMT survey administered in 1991 in order to determine the factors affecting adoption of advanced manufacturing technology. The questions covered a number of areas relevant to understanding the prevalence and consequences of this technology, as well as the reasons for slow adoption.

The survey found more than one-third of all plants reporting that at least 50 percent or more of their production operations depended on CAD/CAE/CAM software; about 21 percent of plants reporting that at least half of their production operations depended on FMS/NC/CNC/Robots; and only 5 percent reporting that half of their operations depended on materials handling technologies (AGVs and similar equipment). Very few plants had invested as much as $1 million in each of these groups of technologies in the previous three years. This is perhaps not surprising for CAD/CAM, which is mostly less expensive software, or for AGVs, which are infrequently adopted. However, it seems that few plants were acquiring large numbers of moderately expensive, high technology production equipment if more than 90 percent of plants invested less than $1 million in FMS, NC/CNC, and robots combined over a three-year period.

Table 3. Percentage of Establishments with Characteristics Related to Advanced Technology Use in Selected Manufacturing Industries (SIC 34-38) (Survey of Manufacturing Technology, 1991)

	CAD/CAE/CAM	FMS/CNC/Robots	Material Handling
Over 50% of operations depend on advanced technology (all plants)	36.11	21.04	4.85
Invested at least $1M in last 3 years (all plants)	3.37	9.49	1.02
Time to full operation no more than 6 months (adopters)	90.72	82.71	83.17
Significant increase in education/training cost:			
Adopters	20.45	16.84	6.63
All plants	13.45	10.82	2.57
Education/training cost over $50K in last 3 years:			
Adopters	11.53	13.12	5.13
All plants	7.88	8.65	2.07
Education/training cost among top 3 problems in last 3 years:			
Adopters	19.51	21.84	14.29
All plants	13.36	14.36	5.67
Education/training/skills among top 3 barriers in next 3 years (all plants)	20.51	26.08	12.49
Cost of equipment/software, lack of benefits among top 3 barriers in next 3 years (all plants)	63.14	68.48	52.97
Benefits (adopters)			
Reduced labor costs	54.66	65.04	60.09
Improved quality	71.78	75.94	39.31
Greater flexibility	43.70	30.58	31.63
Reduced inventory	4.18	10.75	39.10

Industries: Fabricated metal products (34), industrial machinery (35), electronic/electrical equipment (36), transportation equipment (37), instruments and related products (38)

CAD/CAE/ CAM = computer-aided design/computer-aided engineering/computer-aided manufacturing
FMS/CNC/Robots = flexible manufacturing cells or systems, numerically controlled/computer numerically controlled machine tools, pick and place and other kinds of robots
Material Handling = automatic storage/retrieval, automated guided vehicle systems

Source: U.S. Department of Commerce 1993 (Tables 1-1 through 1-8)

Most plants did not report the long lead times to full use of the equipment found at the Pirelli plant described earlier. One reason may be that most technology acquisitions were more incremental and not the kind of fully integrated automation strategy pursued by management in that case.

Plants were also asked about the training implications of advanced technology. About 17-20 percent of those adopting CAD/CAM and FMS/CNC/Robots reported that adoption increased their education and training costs "significantly," but only 12-13 percent reported spending over $50,000 on education and training in the previous three years. When all plants, not just adopters, were considered, the share of plants experiencing "significant" increases in education and training was only about 11-13 percent, and only 8-9 percent of all plants spent $50,000 or more on education and training in the previous three years because of the technology. Materials handling technologies, such as AGVs, had much less impact on education and training requirements, even among adopters. Thus, only about 10 percent of plants had to increase training significantly due to advanced technology.

Plants were also asked to give the top three problems they encountered in acquiring or using advanced technologies. About 20 percent of current users of CAD-based programs and automated production equipment other than AGVs reported education and training costs among their top three problems, and a similar proportion of all plants reported that such costs or lack of a skilled workforce would be among the top three barriers to acquiring these technologies in the next three years. However, about two-thirds cited cost of equipment and software as a top barrier, and about 11 percent also cited insufficient benefits from the technology (not shown). Large majorities of adopters cited quality improvements and reduced labor costs as among the top three benefits of these technologies, while flexibility and inventory reduction were mentioned less commonly despite their prominence in much of the literature.

Automated Process Control

One important technology not covered in the SMT is automated process control. This is a relatively early form of manufacturing automation used for manufacturing processes involving liquids or gases, such as chemicals, petroleum, steel, power generation, and food processing (Woodward 1965). Sensors, central control units, and human operators monitor conditions (e.g., temperature, pressure, chemical composition, material flow rates) and activate switches, valves, and other devices to control production according to optimizing formulas. This form of automation has allowed the conversion of production from batch to an integrated, continuous process. With computerization of process controls, systems can also record in a database the measures or readings used to regulate the production process and make them available for subsequent analyses and process improvement. Operators who once worked on the factory floor—opening and closing valves, performing other manual tasks, and watching physical processes—now monitor the entire production system on computer screens in central control rooms off the factory floor (Zuboff 1988).

Although these automated systems are assumed to require fewer workers, this issue is not well studied. Vallas and Beck (1996, p.354) noted in passing that the introduction of computerized process controls in pulp and paper mills reduced crew sizes, but they did not give any specific figures. Zuboff (1988, p.248f.) noted that managers in the pulp and paper mills she studied felt pressure from their superiors to justify spending on automation based on the number of operator jobs it eliminated, but she interpreted this more as a ritualistic demand and also provided no specific numbers on operator employment before and after the switch from batch production to computerized process controls. Fernandez (2001) found that no operator jobs were eliminated when a new state-of-the-art automated food-processing plant replaced an antiquated facility. However, the technology did upgrade skill requirements through changes in the plant's occupational composition because a greater number of skilled maintenance workers, particularly electricians, were hired to maintain the new equipment (for further discussion of this case, see Handel 2003).

Zuboff (1988) and Hirschhorn (1984) are the most prominent researchers arguing that computerized process controls increase the skill demands within existing jobs. They noted that this form of automation reduces physical labor and increases the amount of thinking needed for operators' jobs. From the control room, operators deal with information rather than things. According to this view, the new technology requires more theoretical knowledge, abstract thought, and procedural reasoning. Automation tends to reintegrate tasks, gives workers responsibility for expensive equipment (often linked together into complex systems), and requires workers to have a more conceptual understanding of how the many parts and stages of a complex process work and fit together. In addition, information technology for the first time makes a wide range of business and production data easily available to all workers for possible analysis. Workers now have at their fingertips information that was previously difficult to assemble and was restricted to managers. They can track output and quality statistics and conduct their own experiments to improve processes. Enlightened managements seek to broaden the operators' role, though there are many cases in which management seeks to limit this form of operator involvement (Zuboff 1988, pp.246ff.).

Zuboff summarized the difference between the operator's job in three pulp and paper mills before and after the installation of computerized process controls.

> Accomplishing work came to depend more upon thinking about and responding to an electronically presented symbolic medium than upon acting out know-how derived from sentient experience…It encompasses a shift away from physical cues, toward sense-making based more exclusively on abstract cues; explicit inferential reasoning used both inductively and deductively; and procedural, systemic thinking…A theoretical conception of the total process is essential (Zuboff 1988, pp.95f.).

However, both Zuboff (1988) and Vallas and Beck (1996) noted that managers often restricted operator training and input, either to protect their own position and control over knowledge or because they embraced an ideology of automation that privileged engineering expertise over the contributions that operators could make on the basis of their experiential knowledge (see also Shaiken 1984).

Neither case had much specific information on the duration or kind of training operators received. In a reconditioned, unionized plant in which operators had about ten years of schooling, managers were especially keen to limit operator training and keep decision making out of operators' hands although they had shown themselves capable and motivated to gain more knowledge and to apply it (Zuboff 1988, pp.253f.). In another newly built plant, almost half the operators had one or two years of college and operators received several weeks of classroom training in basic math, physics, chemistry, and the pulp manufacturing process, though even here management limited learning and autonomous decision making among operators in favor of "machine intelligence and managerial control" (Zuboff 1988, pp.90,270ff.,390). However, even Vallas and Beck

(1996, p.355), who are more critical of existing management practices than Zuboff, acknowledged that the switch from batch to computerized continuous process production increased operator skill requirements and contradicted Braverman's (1974) deskilling argument, at least for this technology.

Finally, given the common-held view that skills and wages track one another, it should be noted that although operators in automated pulp and paper mills had responsibility for more equipment and a larger swathe of the total process than previously, managers denied requests for higher pay from both the unionized workers in the older plant and the more educated workers in the new plant (Zuboff 1988, pp.298ff.,412f.).

Numerically Controlled Machine Tools

The skill implications of numerically controlled (NC) and computer numerically controlled (CNC) machine tools have received more attention than most IT production technologies, particularly since Braverman (1974) claimed they reduced skill requirements for blue-collar workers and increased inequality between blue- and white-collar workers. The case was considered particularly revealing because the new technology affected machinist occupations, which were among the highest-paid blue-collar occupations.

Numerically controlled machine tools were controlled by programs on punched paper tape, punched cards, or magnetic tape that were read by the machine's control unit and contained instructions that automatically guided the machine through its cutting path and monitored a job's progress, eliminating manual operations and control previously performed by a machinist. The programs translated specifications previously contained in blueprints into mathematical descriptions of parts and cutting tool paths. Once written and debugged, the programs could be used to produce identical parts in unlimited numbers automatically. The programs could also be stored for re-use at a later date or as the basis for a modified program that could be used to produce a slightly different part. In the U.S., technical workers in a separate department off the shop floor usually wrote the NC programs, removing planning skills from the machining process. Beginning in the 1970s, CNC machine tools replaced more primitive NC devices with minicomputers and later microcomputers, permitting greater flexibility in the writing and editing of programs, including a user-friendly, menu-driven program interface at the machine itself that permitted the operator to write or edit programs without having to know a programming language (Noble 1979, p.23; Giordano 1992).

As noted, the SMT gave some indication of the incidence of NC/CNC tools. Further detail is available from Kelley's (1989) survey of nearly 1,400 establishments in twenty-one manufacturing industries in 1987. Kelley found that 47 percent of metalworking plants had installed one or more computer-controlled machines, but that even in those establishments most workers involved in machining tasks worked on traditional, non-programmable machines. Overall, only about one-quarter of blue-collar workers who used machine tools worked with an NC or CNC machine in 1987 (Kelley 1989, pp.302f.). Other studies also found similarly small proportions of machine tool users operating NC/CNC equipment in the early 1980s (Keefe 1991, p.516).

Most researchers have devoted attention to the effects of NC/CNC on the skill content of jobs rather than changes in the relative or absolute numbers of different kinds of machining jobs. Most research takes Braverman's (1974, pp.199ff.) work on deskilling as the starting point. He argued that NC/CNC replaced skilled machinists with a relatively large number of unskilled machine operators and a handful of skilled, white-collar programmers.

Other research supports Braverman's position. David Noble (1979) described the development of NC machine tools in the 1950s as displacing an earlier analog technology that never achieved great market penetration, called record-playback, which retained a larger role for skilled machinists. The alternative technology recorded a machinist's movements on a template and stored them for repeated use in production. Noble acknowledges that both manual methods and record-playback could not produce parts to the tight specifications of the Air Force, which was the major sponsor of NC development. However, record-playback did not need new technical skills, a special corps of programmers, and expensive computer units. Record-playback machine tools would have been more affordable than NC for smaller machine shops that did not need to produce to such demanding standards.

Like Braverman, Noble attributed the success of NC to an ideology of engineering and managerial control that valued automation as both a symbol of progress and a method of reducing dependence on expensive, skilled manual workers who had the power to control their own work pace. Noble cited major labor conflicts at aircraft manufacturers as a significant motivation for the choice to develop NC over record-playback. He claimed the main attraction of NC was that it offered the possibility of centralizing knowledge and control in the hands of management and programmers off the shop floor, incorporating skills into the machine, and allowing the greater use of unskilled workers to tend the programmed equipment in place of skilled machinists.

However, unlike Braverman, Noble also acknowledged that deskilling of machining work during the 1960s-1970s had not advanced very far because NC machines could not be operated as automatically as their boosters envisioned. Variations in materials and environmental conditions, limits on the reliability of machines and programs, and the need to safeguard the expensive equipment required skilled machinists to monitor and intervene in the process (Noble 1979, p.41ff.).

Shaiken (1984) also viewed NC/CNC machine tools as a straightforward extension of Scientific Management principles. However, even more than Noble, Shaiken noted that while management often wants to eliminate the need for skilled machinists, the limits of NC/CNC technology itself usually requires a machinist's judgment and experiential knowledge if programs written by non-machinist programmers are to work in practice (Shaiken 1984, pp.80ff.).

Braverman, Noble, and Shaiken all maintained that NC/CNC machine tools do not necessarily imply deskilling metalworking occupations. Management chooses to separate specialized programming functions from shop floor work as much as possible, but it is feasible to add programming functions to traditional machinist jobs.

However, Adler and Borys (1989) argued that NC/CNC is associated with a number of developments that likely increase the skill demands of factory jobs. Low-skill tasks are more easily automated than more-skilled tasks. Shop floor workers need the knowledge and authority to prevent costly mistakes that might damage expensive equipment. The new tools permit machining of more complex parts, smaller batches, and more frequent product changes, all of which require more skill from production workers than producing large batches of standardized goods, which is more predictable and routine work. Automated technology also requires more abstract, conceptual understanding of the technology than manual methods (Adler and Borys 1989, pp.389ff.). This is in direct contrast to the deskilling perspective, which argues that the technology is implemented in a way that reduces the need for conceptual skill among shop floor workers, who merely execute the plans conceived by technical and managerial personnel by monitoring the equipment.

Adler and Borys found some evidence that the wages of NC operators are equal to those of the highest class of conventional machinist, and they note that the addition of more-skilled maintenance workers and technical workers, such as programmers, increases total skill requirements in automated workplaces and average wages in the machining industry overall. They argued that wages are a key index of skill and that future research should focus on this measure as a critical test of the deskilling/upgrading controversy (Adler and Borys 1989, pp.386,395f.). As noted below, Keefe (1991) performed such a test more formally and found no effect, positive or negative, on the wages of production workers in shops with a high percentage of NC machines.

Some case study research supports the skill upgrading position. Interviews with a small sample of machinists found they viewed NC as involving at least as much or more skill than conventional machine tools because of the software knowledge required, the greater abstraction involved in interpreting programmed instructions compared to blueprints, the faster pace of model changes among NC equipment, and the greater responsibility for preventing costly errors, particularly damage to the more expensive equipment (Zicklin 1987, p.460).

Giordano's (1992) study of a defense contractor that produced mostly in small batches found that machinists believed that running an automatic machine required fewer machining skills, especially if the process went smoothly, since the tool was guided automatically rather than manually. However, they noted that machine set-up required more problem-solving and conceptual skills because the tools and sequence of operations had to be planned from start to finish before beginning the job. The ability of NC machines to perform far more precise and complex operations than was possible with conventional machine tools also increased the complexity of machine set-up. Since the programs written by NC programmers did not consistently work as planned, the production process was often not automatic, at least at the beginning of a job. Machinists often needed to correct problems not anticipated by the programmer and therefore still needed their traditional skills. Understanding NC programming and coded equipment readouts in order to know when and how to intervene also required more formal study and knowledge. Nevertheless, overall judgment and time to proficiency in NC machining were judged lower than in conventional machining, as machinists spent much more of their time simply monitoring the equipment. However, the firm did not lower its hiring standards since the process still required workers with conventional machining skills on the shop floor, though other firms with NC tools did use more semi-skilled operators (Giordano 1992, pp.35ff.,62f.,67).

CNC systems simplified programming considerably by replacing the specialized programming language and codes with pull-down menus and step-by-step queries. As one machinist said, "It has a menu and asks you questions. Like multiple choice questions. They designed it for simplicity. But you have to be an experienced machinist to operate it" (Giordano 1992, p.56; see also Shaiken 1984, pp.99ff.,108f.). In an interesting twist, the simplicity of the interface actually made it easier for machinists themselves to write and modify programs at their machines, and management at the defense contractor permitted this reintegration of planning and execution for work on CNC machines. The increased complexity of the parts that a CNC tool could make and the expanded choices for how to perform operations also increased the complexity of this planning process relative to conventional machine tools. Machinists' traditional math skills were generally sufficient for the new tasks but they had to apply those skills using a more demanding procedural logic. Translating operations that were formerly manual into a sequence of computer instructions made the task more abstract. However, both NC and CNC machines rendered traditional, complex manual skills unnecessary (Giordano 1992, pp.53ff.,71).

In congressional testimony in 1982, a staff economist with the International Association of Machinists (IAM) reported that its 89 members working in a small specialty shop did not perceive the introduction of CNC as deskilling, as they were given training in how to edit the programs in addition to using their traditional machining skills. However, older workers were less comfortable with the new equipment and everyone was dissatisfied with the increased workload, stress, and accidents and injuries that resulted from running the new machines at very high speeds without a program of preventative maintenance. However, in a contrary case, IAM members working for the service department of an airline were denied access to a free two-week training program offered by the equipment vendor, as the company preferred to send an engineer, programmer, and supervisors instead. Two of the machinists took the manuals home at night and taught themselves how to program the machine manually in six months, though they were officially forbidden to perform any programming or editing themselves by management (Bittle 1983, pp.177ff.,193ff.).

Some survey data also confirms that most plants using NC/CNC technology do not generally pursue a deskilling strategy. Kelley (1989) found that of the 47 percent of plants with NC/CNC tools in 1987, more than half (56%) allowed at least some workers in traditional machining occupations to write programs or edit programs written by others at least occasionally. Among the 25 percent of machining workers using NC/CNC machines, 14 percent wrote programs regularly, 17 percent wrote them occasionally, 26 percent edited them regularly, and 40 percent edited them occasionally. Overall, two-thirds of workers who used NC/CNC had some programming responsibilities (Kelley 1989, pp.303f.).

These numbers suggest that although most plants did not adopt a strong Scientific Management philosophy with respect to NC/CNC machine use, it does not follow that a high proportion of machinists were performing programming or editing tasks in the late 1980s. If in 1987 only 25 percent of machining workers used NC/CNC at all and two-thirds of them performed some programming tasks, this implies that only about 17 percent of all workers in machining occupations performed any kind of NC/CNC programming tasks, many of which were relatively simple and infrequent. While there is little evidence of deskilling, there is equally little evidence of massive skill-biased technological change.

In addition, contrary to the implications of the theory of skill-biased technological change, Kelley found in a follow-up survey that a more educated workforce had no impact on productivity in plants using NC/CNC technology (Kelley 1996, p.392).

Keefe (1991) analyzed wage data collected by the Bureau of Labor Statistics for the non-electrical machinery manufacturing industry between 1975 and 1983. This industry accounted for an estimated 50 percent of the stock of NC machines at the time (Keefe 1991, p.504). In cross-sectional and fixed-effects multiple regression analyses that controlled for a large number of covariates, Keefe found the proportion of machine tool users operating NC machines in a shop had no significant effect on the mean wages of its production workers. The proportion using NC had a small negative effect on skill levels in the plant, as measured by scales constructed from the *Dictionary of Occupational Titles* (Keefe 1991, pp.514f.). Weighing both the deskilling and post-industrial views, Keefe concluded, "The spread of microelectronics appears, instead, to have left machine shops unchanged in many respects…" (Keefe 1991, p.517). This finding contradicts both the deskilling position and the skill upgrading argument, and is more consistent with Spenner's (1988) thesis of technology's limited effects on skill demands.

Robotics

The most common definition of an industrial robot comes from the Robotic Industries Association, a trade association, which defines robots as "a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions..." (Hunt and Hunt 1983, p.8). Robots can be programmed using a programming language, leading the manipulator through a series of steps manually, or operating a controller while the robot records the motions for subsequent replication. The first industrial robot was the Unimate made by Unimation in the early 1960s, but robot use is not believed to have increased much until the late 1970s (Flamm 1988, pp.273f.).

While recent data are sorely lacking, early reports claimed that the most common applications for robots were welding, painting, and materials handling, which included placement/removal of parts in a machine, transferring parts between different machines, and loading/unloading pallets. Less common applications included inspection and assembly. It is no doubt still true that robots are often used for tasks that are repetitive, hazardous, or otherwise undesirable, but they can also achieve levels of precision not possible with manual methods, particularly in electronics assembly. Likewise, robots came to be used in wafer fabrication in the semiconductor industry and similar clean room environments because they reduced contamination, not because they were cheaper than human labor (Martin 1982, pp.5f.,9; Flamm 1988, p.303).

The possible employment implications of industrial robots exert tremendous popular fascination. In 1986, a Roper poll found that 63 percent of adults thought that the use of robots on assembly lines would increase unemployment despite retraining efforts and 53 percent favored "severely limiting" their use. A few years later (1989), a Gallup poll found that 52 percent of adults expected that robots would replace most assembly line workers by 2000 (see Public Opinion Online, Roper Center at University of Connecticut, http://www.ropercenter.uconn.edu/).

Even some analysts made exaggerated or extreme predictions. Richard Cyert predicted that automation would reduce manufacturing employment from 22 percent of the workforce in 1982 to 5 percent or less by 2000 (*Business Week*, 11/22/82, p.40F). A leading analysis of robotics considered it possible that robots would replace almost all operative jobs in manufacturing by 2010 (Ayres and Miller 1983, p.51). A study by the Society of Manufacturing Engineers predicted that programmable automation would replace half of all direct labor in final auto assembly by 1995 (*Business Week*, 3/26/79, p.94). In the early 1980s, the Secretary of Labor said, "by 1990, half of the workers in any factory may well be engineers and technicians and other white collar specialists, rather than the current blue collar workers" (quoted in Hunt and Hunt 1983, p.2).

Analysts also frequently attributed the competitiveness problems of U.S. manufacturing in the 1980s to lower rates of robot use compared to Japan. However, some of the more extreme claims regarding the labor-saving implications of robots in Japan were shown to be exaggerated (Lynn 1983, p.21; Flamm 1988, pp.319f.; Shaiken 1984, p.156). Indeed, some argued that American manufacturers were much more predisposed than their Japanese competitors to see technology alone as a way to fix problems by reducing labor costs. Rather than soliciting input from front-line workers, American firms favored centrally-controlled computer systems that minimized input from production workers in areas such as quality control and inventory reduction (Flamm 1988, pp.316,319).

In general, it seems that most of the hopes and fears of the 1980s regarding both the promises and perils of robotics were misplaced. An industry observer recently reflected on the history of industrial robotics and noted, "Every few years, a new technology explodes onto the scene, promises everything, dazzles briefly, and then fizzles. Robotics is one such technology that seemed to have it all, but then, for a host of reasons, never took off as quickly as expected and never caught hold across a broad range of industries" (Philips 2000). Many of the early pioneers, such as Unimation and Cincinnati Milacron, went out of business; and larger entrants, such as General Electric and General Motors, suffered significant setbacks and cut back their robotics operations (Philips 2000).

General Motors (GM)'s experience in the late 1980s was one of the most widely publicized failures. GM responded to surging Japanese imports with massive investments in automated equipment (including industrial robots), believing automation to be the key to renewed competitiveness. However, the software and equipment were bug-ridden and failed to operate properly, and productivity remained low. In fact, horror stories of automatic equipment smashing into other equipment or work in progress and failing to deliver parts, paint sprays, or welds to the proper place were reported widely. By the early 1990s, even GM executives recognized the initiative was a failure (Keller 1989; "When GM's Robots Ran Amok," *The Economist*, 8/10/91).

Other research in the early and mid-1980s indicated that robotic equipment did not work well for two to five years and the break-in period caused extreme stress for plant managers (Skinner 1983, p.105; Hunt and Hunt 1983, p.53; Jurgens, Malsch, and Dohse 1993, pp.189,199,359).

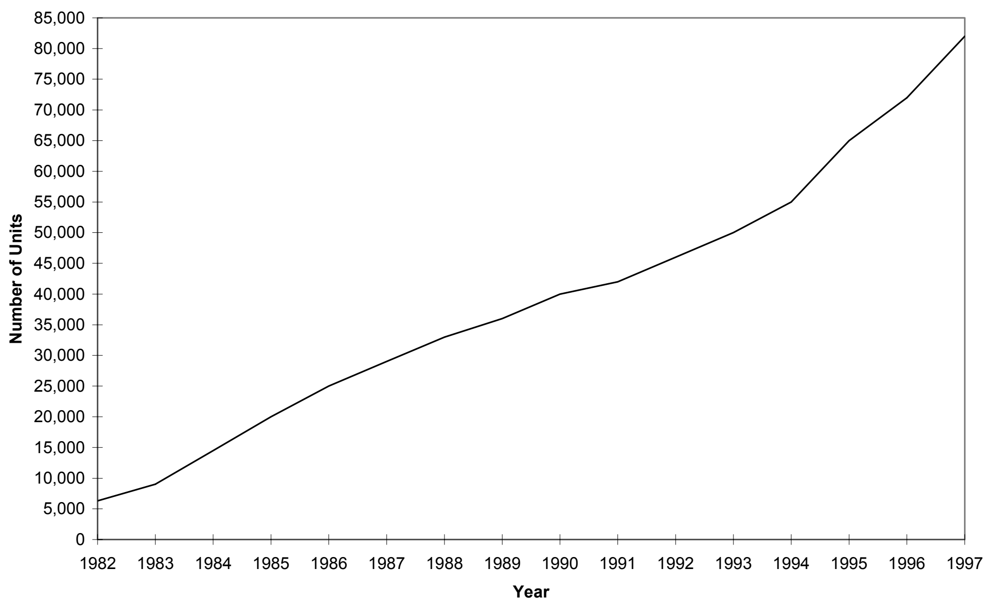
However, these problems may have reflected the early stage of the robotics industry. Recently, industry observers claimed there have been significant improvements in robot reliability, versatility, and ability to communicate with other factory software (Philips 2000). Certainly the data in Table 3 do not indicate such serious transition costs, though the absolute numbers of robots remains rather low even today, as discussed below.

It is probable that there are large, unanticipated costs associated with implementing highly integrated and relatively untried systems, but that many of these problems can be worked out over time. For example, the highly automated baggage handling system built as part of the new Denver International Airport in 1994 received a brief moment of fame for cost overruns, repeated delays, and test runs that sent luggage flying, tore them open, failed to operate at all, and had difficulty reading bar codes, requiring extensive manual baggage sorting (Myerson 1994). However, the system does not generate such negative press any more.

Recent media accounts of DaimlerChrysler's $700 million Jeep plant in Toledo, Ohio also paint a brighter picture of auto assembly automation. The plant uses laser-guided robot forklifts to deliver parts to the assembly line and other robots to weld the skeletons. Plant managers say the robots and improved processes reduce labor requirements by 1,000 jobs. However, the report does not make much of the fact that 80 percent of the 2,100 plant employees still work on the assembly line, another 14 percent are skilled workers, and 5 percent are managers. These staffing ratios seem a far cry from both the lights-out factory and a workforce composed mostly of technical workers. Likewise, a significant part of any labor savings in this plant surely reflects its outsourcing of significant operations to lower-wage, non-union suppliers who do not pay over $24 an hour plus benefits to unskilled workers, as does DaimlerChrysler (Bradsher 2001; Siekman 2002).

In contrast to NC/CNC machine tools, most research on robotics has been concerned with changes in employment levels, rather than changes in the task content of jobs. While reliable figures are scarce, the Robotic Industries Association (RIA) has a time series on the total number of robots used by its members, reported in Figure 1. The figure for 1993 (50,000) is remarkably close to the SMT 1993 estimate (52,218), but the universes differ so it may reflect coincidence more than the reliability of the RIA figures. The most recent estimate of the total robot population uncovered from this source is 82,000 in 1997 (Berinstein 1999, p.48).

Figure 1. U.S. Robot Population, 1982–97



Source: Berinstein (1999, p.48), from Robotic Industries Association, unpublished figures

Numerous early studies and even some robotics industry officials seemed to agree that the estimated displacement effect was roughly two workers per robot, assuming no increase in output as a result of cost savings and price reductions (Hunt and Hunt 1983, p.69; Ayres and Miller 1983, p.50; Watanabe 1987, pp.2,11,91,117,187; Kaplinsky 1987, p.85; Munson 1983, p.201).

Hunt and Hunt (1983, p.50) estimated that the robot population in 1990 would be somewhere between 50,000 and 100,000. On this basis, they estimated that robots would displace 6-11 percent of operatives and laborers in the auto industry between 1980 and 1990 and 1-2 percent of semi-skilled jobs in other manufacturing industries over the same period, not including any possible effects of rising demand that might result from lower output prices (Hunt and Hunt 1983, p.82). However, the authors also noted that replacement needs in these occupations as a result of quits and retirements were projected to exceed even their maximum estimates of job displacement due to robots (Hunt and Hunt 1983, pp.93ff.). The authors concluded that the diffusion of robots would "have little influence on employment trends to 1990 except in highly specialized situations," such as auto factory paint shops (Hunt and Hunt 1983, p.98). This assessment is supported further by the fact that the actual number of robots in use in 1990 according to the RIA estimate was only 40,000 (see Figure 1), 20 percent below the lower-bound estimate of the robot population used in Hunt and Hunt's calculation. Even the figure for 1997 was only about midway between their lower- and upper-bound estimates for 1990.

Research on how robots change the skill content of existing jobs is even sparser. One study of Ford Europe in the early 1980s found that after the installation of robots, the company provided its maintenance workers with ten days of training in basic electronics, twelve days in microprocessors, and four days each in pneumatics, hydraulics, and fluid logic (Kaplinsky 1987, p.133). Similarly, Hunt and Hunt (1983, p.121f.) reported that experienced machine repairers and electricians needed only three months of training or less to handle robots. User-friendly interfaces also resulted in short training times for technicians and other skilled workers who might need to reprogram robots.

The auto industry has long been recognized as the leader in the use of robots. Perhaps the most satisfying case study of both the employment and job task content implications of robotics is Milkman and Pullman's study (1991) of GM's Linden, NJ assembly plant in 1985-86, after it was rebuilt to incorporate state-of-the-art robots and other elements of industrial automation. After the modernization, which cost over $300 million in current dollars, the Linden plant was one of the country's most automated assembly plants—replacing the assembly line with 219 robots (192 for welding, 12 for painting, 6 for sealing glass, 9 for training and use as spares), 186 programmable logic controllers to program the robots, and 113 automated guided vehicles to carry car bodies to different work stations. The plant also adopted a just-in-time (JIT) inventory system, quality measures such as statistical process control, and employee involvement groups (Milkman and Pullman 1991, pp.127f.).

The number of production workers at the plant declined from 4,460 in 1984 to 3,283 in 1987, or 26 percent. However, this decline reflected many factors in addition to changes in production technology: GM's declining market share; increased outsourcing of components; increased organizational efficiencies; and a changeover at the plant from Cadillacs and Buicks to Chevrolets, which required only about one-third the number of parts and far less trim (Milkman and Pullman 1991, pp.128f.,142; Milkman 1997, p.148f.).

Table 4 gives a breakdown of the changes in employment levels and proportions for different occupations and departments in the plant. While the body and paint shops were the most automated and received 206 out of the 210 production robots, their share of the total plant workforce showed little change after the plant modernization. The greatest loss in both absolute and relative terms was in the trim department, almost surely reflecting the outsourcing of seat cushions and the shift from luxury to budget car models, among other reasons, rather than more advanced technology. The relative number of inspectors also fell significantly, while the share of supervisors fell modestly, reflecting organizational changes such as the quality, JIT, and employee involvement. The real impact of automation seems to have been the growth in the share of skilled workers, mostly electricians necessary to prevent costly downtime. The share of salaried workers other than supervisors remained unchanged (Milkman and Pullman 1991, p.129ff.; Milkman 1997, p.149).

Table 4. Employment by Occupation and Area Before and After Automation, General Motors Linden, NJ Assembly Plant (1985-86)

	Raw			**Percentage**		
	Before	After	Difference	Before	After	Difference
Production	4629	3110	-1519	82.2	76.6	-5.6
Body shop	568	385	-183	10.1	9.5	-0.6
Paint shop	681	520	-161	12.1	12.8	0.7
Inspection	425	177	-248	7.6	4.4	-3.2
Trim	1385	779	-606	24.6	19.2	-5.4
Chassis	1020	755	-265	18.1	18.6	0.5
Other	550	494	-56	9.8	12.2	2.4
Skilled trades	235	425	190	4.2	10.5	6.3
Supervisors	156	90	-66	2.8	2.2	-0.6
Other salaried	608	437	-171	10.8	10.8	0
Total	5628	4062	-1566			

Source: Milkman (1997, p.148)

Milkman noted, "contrary to the fear of massive job displacement that is so often associated with new technology, it eliminated a surprisingly small number of jobs" (Milkman 1997, p.148). Commenting on the changes in absolute employment, Milkman and Pullman concluded, "It appears that the change in car model actually had a greater impact on employment levels than the technological changeover itself" (Milkman and Pullman 1991, p.131). For all the talk about robot displacement, the effects seem surprisingly small. Even if one were to attribute all of the absolute employment decline in the body and paint shops (-344) to the installation of 206 robots (almost certainly an overstatement given declining demand and other changes affecting the plant), this implies displacement of less than 1.7 jobs per robot.

The content of jobs also showed a mixed picture. In a sample survey of the plant's skilled trades (n=52) and production workers (n=217), half of the skilled trades workers said they used a computer on their job, mostly PLCs, but only 5 percent of the surveyed production workers reported computer use. In general, the authors found only modest changes in the task content of jobs except for electricians, who needed knowledge of electronics and ability to program PLCs after the installation of automated equipment (Milkman and Pullman 1991, pp.132ff.).

Table 5 reports additional results from Milkman and Pullman's survey on the skill levels required by skilled and unskilled production workers before and after the plant modernization. Using retrospective questions, the survey found that unskilled workers were actually less likely to report that accuracy, concentration, judgment, and memory were very important for their jobs, dropping from roughly 60 percent to 45 percent in most cases. Those reporting that problem-solving, reading, and math skills were very important held steady at about 40 percent, 15 percent, and 7 percent respectively. Production workers were asked how long it would take new workers to learn how to do their job well before and after the changeover; the median responses were 5 and 3 days, respectively. The corresponding figures for skilled workers jumped from 6 months to 12 months. While most of the decline among production workers reflected the change in auto model and the transfer responsibility for parts quality back to vendors, the few production workers using computers noted that they were simple to operate. When asked if they would benefit from more training, less than 10 percent of unskilled workers responded positively. Results were qualitatively similar in the more automated body and paint shops as in the plant as a whole (results not shown) (Milkman and Pullman 1991, pp.139ff.).

Table 5. Self-Reported Skill Requirements of Unskilled and Skilled Production Workers Before and After Automation, General Motors Linden, NJ Assembly Plant (1985-86)

	Unskilled Workers			**Skilled Workers**		
	Before	After	Difference	Before	After	Difference
	Percentage Reporting Skills "Very Important"					
Accuracy/precision	71	63	-8 *	46	73	27 ***
Concentration	58	48	-10 ***	42	60	18 **
Judgment	57	47	-10 ***	69	71	2
Memory	63	42	-21 ***	56	81	25 ***
Problem solving	41	37	-4	52	73	21 ***
Reading	17	14	-3	23	31	8
Math	8	6	-2	17	19	2
Training time (median)	5 days	3 days	-2 days	6 mos.	12 mos.	6 mos.
Need more training		<10%			71%	

Note: Significance tests not reported for last two rows.

* p < .10 ** p < .05 *** p < .01

Source: Milkman and Pullman (1991, pp.140f.)

This is not to say that nothing had changed. Most workers were pleased with the changes in working conditions in the welding area, which eliminated previously high levels of dirt and dangerous fumes. Few wanted to return to the previous conditions, but this was not because skill requirements had increased. One worker, referring to the body shop, said "The jobs are real easy over there now. Most of the guys just have buttons to push for loading up stuff, and robots do it" (Milkman 1997, p.155).

The situation among the skilled trades was much different. For most, though not all, of the skill dimensions, workers reported large increases in skill requirements; these changes were concentrated heavily among the tradesmen servicing the new equipment (not shown). They also reported that their total time to proficiency increased from 6 months to 12 months. Nearly three-quarters of all skilled workers felt they would benefit from additional training, including 87 percent of those working most closely with high tech equipment (not shown). Clearly, the IT-based equipment required greater knowledge of electronics repair than the previous mechanical production technology (see also Fernandez 2001).

In sum, both the proportion of skilled workers and the level of skill required by their jobs increased. However, even after a substantial modernization effort, skilled workers and supervisors remained less than 13 percent of total plant employment, while unskilled production workers were nearly 77 percent, down from 82 percent. This supports the view of another study that noted, "the full automation of assembly operations in car production is not in sight" (Jurgens, Malsch, and Dohse 1993, p.362).

If skill could be reduced to a single dimension, the total skill requirements in the Linden plant would be the sum of that figure for skilled and unskilled workers weighted by their proportion of total employment. Given the continued need for large numbers of unskilled workers in the modernized plant, any skill upgrading of maintenance workers will be diluted in the larger scheme of things by their small relative numbers.

The Linden case is also consistent with a study of the five largest Japanese car manufacturers, their major suppliers, and a sample of small subcontractors in 1983. This study concluded that, despite popular impressions of the role of advanced technology in Japanese success, "The assemblers and major component manufacturers believed that the overall employment impact of the microelectronic technology was marginal" (Watanabe 1987, p.66). Far more important for overall employment levels were product demand, product mix, car design, work organization (i.e., industrial engineering), and continuous improvement through quality circles (Watanabe 1987, p.66). However, the study authors also cautioned that improvements in design are not entirely separable from advances in computer technology. CAD systems can reduce the number of parts and welds, thereby reducing labor requirements (Watanabe 1987, pp.118,141).

Despite the continued expansion of robot use in the 1990s (Figure 1), a previous assessment of the potential for robots to revolutionize industrial production is probably still well taken:

> ...there are only a handful of major uses in which they are currently a cost-effective solution for manufacturers. Rather than being part of a pervasive, evolutionary change that is spreading through all industry, industrial robot use has expanded in fits and starts, as small and narrow niches have been conquered by more capable machines...One would be well advised to be skeptical of technological optimists who...project veritable tidal waves of robots inundating manufacturing in the medium-term future (Flamm 1988, p.317).

CHAPTER 3: CLERICAL AND RELATED OFFICE WORK

General

Computers and automation are not restricted to manufacturing. In fact, computers are used far more frequently by white-collar than blue-collar workers (Krueger 1993). As with manufacturing jobs, the question is what impact IT has on the occupational composition of employment and the skill content within occupations. Like the debates over the nature of manufacturing work, issues of deskilling and upgrading have preoccupied many studies of trends in office work.

Deskilling theory argues that computers replace more-skilled office work with typing pools and data entry jobs, transforming office work into white-collar "sweatshop" jobs involving long hours of repetitive keyboard work (Braverman 1974). The upgrading position claims that computers tend to eliminate more routine than non-routine work and to decentralize information, making company-wide databases available to front-line workers for the first time. This makes it sensible for firms to broaden jobs by delegating some problem-solving and discretionary tasks downward in order to improve decision-making times (Attewell 1987; Zuboff 1988). Many studies have focused on trends in banking, insurance, and similar work involving high-volume, routine information processing, particularly the skill content dimension, which is reviewed in detail below.

It is also important to note some limits to office automation in the case of non-routine clerical jobs. Observers have long recognized some problems with the simple view that computers will eliminate certain kinds of clerical jobs simply by speeding up execution times. Iacono and Kling (1991) noted that secretaries perform a variety of tasks, such as answering phone calls, photocopying, and typing documents. If a word processing program reduces the time needed to format a document by 50 percent but the secretary only spends 10 percent of the day formatting documents, this means only a 5 percent gain in overall productivity. In addition, word processing introduces new capabilities that may improve the quality of the final product but increase the required total work time (Iacono and Kling 1991, p.216).

This view is supported by a study of the introduction of laptops to field auditors in the Internal Revenue Service in 1986. Agents were pleased with the ability to save time on routine calculations, keep track of information, and produce professional-looking reports, but only 15 percent said the laptops reduced overall time spent on a case (Pentland 1994, pp.373,379).

However, there is a possibly more significant consequence of IT diffusion that may be reducing the number of secretaries and similar, non-routine clerical workers, namely the new ability of managers and professionals to perform their own typing and clerical tasks more easily using a personal computer than by relying on clerical assistance. It may not be the increased execution speed that is the critical aspect of computerization, but the reintegration of clerical tasks into managerial and professional jobs that computers facilitate.

Banking and Insurance

Decades prior to the advent of microcomputers, the banking and insurance industries were intensive users of mainframe computers due to the centrality of information management in these industries, primarily various accounting and transactions record-keeping functions. Traditionally, these industries involved high-volume, standardized, labor-intensive, paper-processing tasks performed in centralized "back-office" operations. Computers were well suited to manage and process the vast quantities of information generated in these businesses (Pullman and Szymanski 1986, pp.56,76).

Initially, many operations in banking and insurance required repeated manual keyboard entry of information into centralized databases, which reinforced the use of factory-like operations that were the focus of deskilling accounts of office automation. More recent developments that have tended to reduce data entry and other low-level clerical work include: increased input into databases by users at point of origin (e.g., Automatic Teller Machines (ATMs)); increased use of imaging; greater communication between computer systems; and increased integration of databases and portability of files (Pullman and Szymanski 1986, p.48; Baran 1988, p.689; Carre 1997, p.22). One question remaining is whether increased demand for these services is sufficient to prevent employment declines.

Banking

Specialized computer applications in banking include Magnetic Ink Character Recognition (MICR), introduced in 1958, which encodes customer account and bank routing numbers and other information on checks for electronic reading. Computer networks permitted the growth of electronic funds transfer in the mid-1970s. Diffusion of ATMs began in earnest in the late 1970s. In the late 1980s and in the 1990s, point-of-sale (POS) devices, which allowed retail purchases to be made by swiping credit and later debit cards, spread rapidly (Pullman and Szymanski 1986, p.56ff.).

Many of these changes might seem at first glance to reduce clerical labor requirements, but their employment effects are not well studied or understood. For example, ATMs were often promoted based on predictions of labor cost savings (often greatly exaggerated) that were said to come from elimination of tellers (Pullman and Szymanski 1986, p.55; Hunter et al. 2001, p.413). However, the percentage of tellers in banking remained nearly constant between 1983 and 1997, though the percentage of all clerical workers in banking and insurance declined from about 50 percent to 40 percent over the same period (Handel 2000). It is possible that POS devices contributed to this drop by replacing the use of paper receipts for communicating purchase information to financial institutions with electronic communication. However, this review uncovered no studies that investigated the issue directly.

Turning to the issue of job content, there is a view, expressed since the mid-1980s, that teller positions will be increasingly upgraded to include more sales and lower-level account-management functions, though claims for this trend seem to outrun the actual extent of such skill upgrading (Pullman and Szymanski 1986, p.62; Hunter et al. 2001, pp.414f.). Banks that do pursue this policy also seek to restrain wages at the same time through the greater use of part-timers and other methods (Hunter et al. 2001, pp.415f.,420).

Hunter and Lafkas (2003) studied the relationship between technology, work organization, and wages among customer service representatives (CSR) in 303 bank branches owned by numerous different parent companies in 1994-95. They found that those CSR jobs with the maximum value on their index measuring computerization of non-routine tasks paid 7 percent more than those in branches in which none of these tasks were computerized. By contrast, a similar index for computerization of routine tasks was associated with a larger premium when interacted with an indicator for participation in quality circles (10%). Computerization of routine tasks was also associated with a large wage penalty in branches in which CSR jobs scored one standard deviation below the mean on an index measuring level of discretion on the job (-11%). There were no significant interactions of non-routine computerization and quality circles or the discretion index (Hunter and Lafkas 2003, Tables 4 and 5). The results seem to suggest that computerization of more complex tasks is consistently associated with higher wages, but the larger payoff to computerization of simple tasks under some circumstances (quality circles) and the large negative effects of computerization under others (low discretion) complicate the picture.

Insurance

Computerization also came early to insurance. In 1954 Metropolitan Life became the first insurance carrier to install a computer; by 1963 nearly 300 companies accounting for 90 percent of the industry's employment were either using computers or in the process of installing them. High turnover among the young women who performed much of the routine clerical functions meant that any labor productivity gains from computers could be realized through attrition rather than layoffs, and the businesses were growing sufficiently that overall employment continued to increase (Hedstrom 1986).

The insurance industry had early expectations in the 1950s that computers could dramatically reduce the size of the clerical workforce. However, managers soon realized that automating office work would be a more gradual process. Computers had more technical limitations than anticipated. In addition, difficulties in systems analysis and programming, inadequate consultation with current job incumbents, and the unrecognized complexity of the work process performed by clerical workers all inhibited the progress of office automation. It was not uncommon for office automation projects to fall behind schedule and produce systems that were disappointing from the perspective of the original goals (Hedstrom 1986).

In the 1960s insurance companies used computers for simple, repetitive transactions, such as billing and claims payments, as well as for generating accounting reports. These operations were centralized into white-collar, factory-like operations. Subsequent automation reduced not only clerical positions, such as data entry, but also positions associated with routine underwriting (risk assessment and policy approval) and rating (premium setting). For many firms the goal became to replace as many skilled workers as possible and rely increasingly on the white-collar factory model for the remaining work, removing knowledge and judgment from the workforce and lodging it in the computer system at least for the more routine operations—a model that conformed to deskilling predictions (Appelbaum and Albin 1989, pp.250ff.).

Claims adjustors in branch offices and the field also used more desktop and portable computers to input information that was then transferred electronically to central databases, eliminating previous requirements for manual data entry from paper forms (though there is evidence that this remained relatively uncommon until the 1990s). The greater use of computers reduced clerical employment but may have also reduced the need for mid-level skills in sales, policy-writing, and claims-processing functions, which could be transferred to relatively skilled segments of the clerical workforce (Pullman and Szymanski 1986, p.76ff.).

Understanding how the potentially offsetting changes in the number and skill content of different occupations affect overall skill requirements in the industry has not been easy or straightforward. In addition, even in the mid-1990s, the spread of computers remained uneven. Some companies still used systems that required multiple data entry and manual underwriting without computer assistance (Carre 1997, p.15).

However, by the 1980s, the business press reported instances of significant net employment reductions and labor cost savings as a result of office automation. One market research survey found that one-third of 400 firms surveyed said they cut clerical labor costs by at least 10 percent, while only about 5 percent of the firms said they cut middle management and professional costs by a similar amount (Harris 1987).

Several case studies of office work in the insurance industry seem to indicate that both the distribution of jobs and the skill content of even lower-level clerical jobs have moved away from the deskilling model and toward at least limited upgrading, though the extent of upgrading within occupations is very difficult to pin down conclusively.

Baran's (1988) study of the insurance industry found cases in which the new wave of computerization facilitated the elimination of unskilled clerical jobs in favor of new, more-skilled clerical positions. As computers took over more of the routine data entry and even somewhat complex calculations, these jobs were given a limited amount of judgment and decision making in matters like routine rating and underwriting, interaction with agents, claims processing, and quality control—tasks previously reserved for professionals. In contrast to Braverman's model of a white-collar proletariat spending their entire day performing deadening keyboard tasks, Baran concluded that "workers in the new clerical jobs, although closely circumscribed in their decision making, are a long way from the typing pool" (Baran 1988, p.691). Contrary to deskilling theory, computers seem to be reintegrating job tasks among clerical workers in insurance. However, contrary to the large claims made for skill upgrading, most of the changes seem to be qualitatively modest and unlikely to tax the abilities of most of the current job-holders.

Professionals' jobs were also upgraded as they involved more time spent on exceptions that could not be handled by the new clerical workers and on the development and marketing of new products. The proliferation of specialty services that were supported by computers but could not be automated also increased the need for skilled professionals. Professionals and clerical workers increasingly worked together as part of integrated teams serving all the needs of different classes of customers (e.g., market segment, geographic region), rather than being separated into different functional departments (Baran 1988, pp.691f).

Nonetheless, even if computers increased job skill requirements, Baran found that the insurance industry also increased its use of female workers in all occupations at a much faster rate than the economy overall, and real wages in the industry declined faster than average. Firms moved operations from major cities to suburbs in order to tap into labor markets with educated, married women with family responsibilities who were willing to work part-time for lower wages (Baran 1988, pp.701ff.; 9to5, National Association of Working Women 1985, p.13f.). Skill requirements may have increased somewhat, but the companies used careful strategies to ensure that wages did not rise also.

Appelbaum and Albin (1989) found instances in which firms pursued a deskilling strategy and sought to routinize as many tasks as possible. However, other firms followed a different path. In the early 1980s, one firm created a new, multi-skilled customer service position that had some sales responsibilities and access to underwriting and rating databases in order to answer customer questions and complaints. These customer service representatives had extensive product knowledge and discretion to make decisions up to a certain dollar amount, though computers also monitored their calls to maintain productivity levels. The other main skilled clerical position in the firm was the claims representative. Claims representatives could settle most claims and issue a check with the aid of computer software, which automatically processed routine claims and provided decision guidelines for the rest. The new customer service and claims jobs involved decision making that was previously performed by professional employees. The company eliminated almost all less-skilled clerical jobs, such as mail handling, data entry, coding, and verifying, as well as professional adjuster jobs (Appelbaum and Albin 1989, pp.253,255).

The company hired high school and college graduates in roughly equal numbers for the skilled jobs and provided five weeks training covering insurance and telephone and computer skills, followed by 3-6 months of on-the-job training. Employees were also encouraged to take more insurance courses on their own time, paid for by the company. However, consistent with Baran's results, the starting pay for these jobs was no better than average for clerical jobs ($17,560 in 2001 dollars), and mobility opportunities were limited as a consequence of the reduction of lower-level management positions and increased use of college graduates in upper management. Computerization and work reorganization also allowed the company to reduce overall employment by more than half while maintaining the same volume of business (Appelbaum and Albin 1989, pp.254f.).

Another case study of insurance companies in the mid-1990s found a similar process. Microcomputers integrated customer service functions into a new position with broader responsibilities, eliminating typing pools and much routine filing and data entry (Carre 1997, p.32f.). Educational requirements for underwriters in one firm rose to the point that the company recruited only college graduates for these positions. Computers eliminated or shifted more routine underwriting tasks to less-skilled workers but also created more opportunities for skilled underwriters by enabling increases in product complexity and the amount of financial and other information available for decision making. Reorganization also eliminated buffers between underwriters and sales agents in the field, requiring underwriters to communicate more with the agents. "In this context, college graduates are seen as more adaptable and more desirable candidates" (Carre 1997, p.26). However, it is possible that further automation will eliminate underwriter jobs in the future as more of the underwriting function is built into the computer system and performed by agents in the field (Carre 1997, pp.26,31). This particular company had a long commitment to avoiding layoffs, including those resulting from technological change, but this policy was feasible in part because of a general policy of lean staffing (Carre 1997, p.34).

In addition, changes may result from workplace reorganization that is independent of new technology. A different insurance company reorganized lower-level clerical work into similarly broader jobs and regionally based teams in order to integrate all tasks associated with a customer's account without any apparent stimulus from new information technology. The reengineered process was simply considered more efficient and effective than the previous functional organization involving more hand-offs between different workers and departments (Carre 1997, p.42).

Attewell (1987) took a broader perspective on occupational change in insurance. He found that the percentage of all employees in insurance in the lowest-level clerical jobs declined steadily from 62 percent to 40.5 percent between 1966 and 1980, while the share of high-level computer occupations (systems analysts, programmers) grew from 5 percent to 18 percent and the share of other high-level white-collar workers (actuaries, approvers, underwriters) rose from 7 percent to 12 percent. There was little evidence of changing skill requirements within occupations over this period (Attewell 1987, p.338ff.). This would seem to contradict deskilling accounts even for the era when computerization was most likely to generate large, centralized, data entry operations. Unfortunately, this review did not uncover a similar study for the period after 1980.

Although technology seems to have reduced routine clerical employment in insurance, there are difficulties in isolating its causal impact because the industry deregulated and began to engage in outsourcing, including offshore production, at the same time new computer technology became available in the 1980s. Deregulation brought new competitors into the insurance market, which reduced profits, especially after interest rate declines in the early and mid-1980s (Pullman and Szymanski 1986, pp.74f.). As Baran observed, "Companies in which paternalism protected job security even through the great depression have recently been rocked to their foundation by layoffs of up to 1500 employees virtually overnight" (Baran 1988, pp.689,695). It is highly likely that substitution of technology for human labor facilitated the layoffs among clerical workers (Baran 1988, pp.695ff.), but it is difficult to disentangle the effects.

In addition, the insurance industry increased the use of home workers in data entry and claims adjustment. These women are independent contractors and paid on a piece-rate basis, though the extent of this practice was limited in the 1980s and its extent remains unclear today (Baran 1988, p.693).

The use of offshore workers in the Caribbean for routine clerical work also began in the early 1980s, but it is not clear how much the insurance industry was or is involved in this practice. Most accounts describe female workers entering data from airline tickets, credit card receipts, and medical claims. In the 1990s, Barbados alone had 2,300 workers in the data processing industry. Wages were less than half the U.S. level, but Barbados in particular also had other attractions, such as an educated and English-speaking labor force, favorable tax laws, and technological infrastructure (Freeman 2000). Recent reports in the popular press suggest that the use of offshore clerical workers has expanded greatly. Scanning technology allows half a million tickets issued to New York City residents for simple infractions to be entered into a database by workers in Ghana earning less than $70 a month, more than twice the average income in that country. The air-conditioned office operates 24 hours a day (Worth 2002). Bangalore, India has become a center for such back-office processing as well as for customer service call centers that handle inquiries from customers in the U.S. and elsewhere (Landler 2001).

At present, the total employment effects of this form of outsourcing probably remain small, but they need to be recognized in any account of the employment effects of computer technology. IT may sometimes upgrade domestic job skill requirements by changing the occupational distribution (automating less-skilled jobs out of existence, increasing the absolute number of more-skilled positions) and by altering the skill content of jobs, but it may also simply facilitate the transfer of existing work outside the country to lower-wage areas.

Survey of Banking, Insurance, and Legal Office Work

One study is particularly notable for its level of detail. In 1986, Pullman and Szymanski (1986) conducted a survey of clerical workers (n=382) and interviewed their managers (n=40) in nine firms in the banking, insurance, and legal services industries in New York City. Nearly three-quarters of clerical respondents and nearly all their managers reported that computer use had increased the skills involved in clerical jobs (Pullman and Szymanski 1986, pp.124,139). However, when asked for the most important cognitive skills demanded by their jobs, workers mentioned accuracy, concentration, attention to detail, good memory, and good spelling and grammar. Even in banking, knowledge of math was not among the ten most important skills (Pullman and Szymanski 1986, p.112). Although computers may have increased job skill requirements, the level of skill required did not seem to be much higher than for traditional clerical work.

In addition, only 12 percent of clerical workers said people in their work unit received significant pay increases as a result of working with computers, though 35 percent said computer skills made it significantly easier for people to receive promotions. Nevertheless, about 85 percent agreed that their jobs had little or no prospects for promotion overall, a circumstance confirmed by managers, who cited high levels of turnover as one consequence (Pullman and Szymanski 1986, pp.160,163ff.). Other contemporaneous studies also found that the introduction of computers did not affect compensation levels (9to5, National Association of Working Women 1985, p.29).

However, Pullman and Szymanski also presented briefly a set of regression analyses that indicated that the number of computer tasks a worker performed was positively related to their annual earnings (Pullman and Szymanski 1986, pp.181ff.). The authors did not discuss the findings in detail so it is not clear how to reconcile this with workers' own perceptions that computer use did not improve wages. It is possible that the different levels of computer use required by jobs in different workplaces caused employers to use more or less rigorous selection procedures so that higher pay was built into jobs requiring more computer skills from the start, while respondents were only aware of the more restricted pay variation within their particular work group. Alternatively, respondents' perceptions may be correct and the regression results could be spurious. Greater computer skill requirements may be associated with firms and jobs that paid relatively well even prior to the introduction of computers.

One further measure of the skill changes resulting from computerization is training times. Nearly half of respondents in this survey worked for companies that provided no formal computer training and that relied instead on a combination of on-the-job training, co-worker assistance, and previous experience. In firms that did provide training, it usually took the form of one week of half-day sessions, though in many cases employees were not aware of the classes or were not permitted by their bosses to take time off to attend them. Nevertheless, only 25 percent of clerical respondents said their company's computer training was inadequate (Pullman and Szymanski 1986, pp.143ff.). Overall, this does not suggest a great deal of skill upgrading within jobs.

Nevertheless, Pullman and Szymanski concluded that the least-skilled clerical jobs were declining because many previously narrow jobs were consolidated into broader jobs; because professionals and others were more likely to input data as an integrated part of their jobs; and because computers enabled greater use of self-service operations. They noted that the ratio of clerical workers to professionals declined as a result of these processes, but even many of the enlarged clerical jobs in their sample were highly repetitive, routine, and frequently accompanied by heavier workloads (Pullman and Szymanski 1986, pp.91,126,136,165).

Other Clerical Work

Clerical work outside of banking and insurance is not easily characterized overall because it is more heterogeneous. Some jobs, such as secretaries, have much greater variety, but others are more routine.

Laudon and Marr (1995) studied IT's effects on the level and occupational composition of employment in two settings similar to banking and insurance in their level of routine clerical functions. They examined employment at the Social Security Administration (SSA) and the Internal Revenue Service (IRS) between 1975 and 1990. Both are large organizations with an extraordinary amount of routine information and paper processing. In 1990, SSA employed 65,000 workers and generated roughly 45 million checks per month. The IRS employed 120,000 workers and maintained earnings records for roughly 200 million employed Americans and 4.4 million other reporting entities. Both agencies experienced dramatic increases in computing capacity in the 1980s. At SSA, clerical workers' share of total employment dropped modestly from 28.5 percent in 1975 to 26.2 percent in 1990, while the clerical share at IRS rose from 24.9

percent to 31.1 percent over the same period (Laudon and Marr 1995). It is not clear what is responsible for the modest character of the changes, but they certainly do not suggest that automation has eliminated clerical work in all routine paper- or information-processing industries.

Mail sorting in the U.S. Postal Service is another setting that involves an extraordinary amount of physical paper processing, and for many years mail-sorting operations remained relatively labor intensive. By the early 1990s the Postal Service processed over 165 billion pieces of mail per year (Baxter 1994, p.146). Prior to the 1960s conveyer belts linked sorting operations, but postal clerks had to memorize processing schemes, read addresses, and insert mail manually into the correct slot in a metal case containing 77 slots. In the 1960s the Postal Service introduced mechanical letter-sorting machines that automatically fed letters to the sorter's station at a rate of one per second; sorters entered the routing code into the machine, which then directed the letter to the proper compartment (Baxter 1994, pp.70ff.). The Postal Service began to use optical character readers (OCRs) during the late 1960s, but they were not cost effective until the 1980s. Improved OCRs were integrated with zip code databases and ink jet printers that sprayed bar codes on pieces of mail, which were then read by bar code scanners and automatically sorted into bins (Baxter 1994, pp.149ff.).

However, despite extensive automation efforts in the 1980s, there has been remarkably little change in the occupational distribution within the Postal Service. The share of supervisory, technical, and maintenance workers rose from 11.5 percent in 1981 to 12.4 percent in 1990. The trends for clerks and letter carriers are harder to calculate because the Postal Service classified part-time workers as a distinct group in the early

1980s, even though they worked mostly in those two occupations. However, it appears that between 1986 and 1990, the share of clerks dropped from about 50 percent of total Postal Service employment to about 49 percent (author's calculations from Baxter 1994, pp.169f.). Obviously, these are not large changes despite the enormous potential for economies of scale in computer-assisted or automated letter sorting in the back-office operations of the Post Office.

In the late 1980s Attewell studied routine clerical work in a wide range of businesses and found that the switch from batch to online, real-time computing was associated with a reintegration of tasks into broader jobs similar to that described for insurance. For example, clerks who had previously only recorded order information now also used the computer system to check inventory, estimate delivery dates, and sometimes check the customer's credit or payment history (Attewell 1992, p.72f.). Attewell was impressed with the upgrading involved but, though the trend is contrary to deskilling, the changes seem more like classic examples of job enlargement rather than job enrichment. Instead of performing a single simple task, most people seem to be doing multiple simple tasks, and it remains to be demonstrated that this has large impacts on either the kinds of workers hired or the wages they are paid.

Finally, one might note a study published in the mid-1980s that predicted (1) computerization would increase productivity so greatly that secretaries, bank tellers, and telephone operators in 2000 could complete as much work by lunchtime as equivalent workers accomplished in an entire day in 1977, and (2) photocopying jobs would be eliminated by the ability to print directly from files stored on computers (9to5, National

Association of Working Women 1985, pp.18f.). Roughly speaking, this implies an annual productivity growth rate of 3.75 percent.[2] While reviewing the research on productivity in these areas is beyond the scope of the present project, data from the Current Population Survey suggest that only the case of telephone operators comes close to this figure (Handel 2000). Needless to say, photocopying has not been eliminated.

Nevertheless, the clerical workforce has declined, as has the ratio of secretaries to managerial and professional staff, also predicted by the study (9to5, National Association of Working Women 1985, pp.9,19; Handel 2000). It is unclear how much of this is purely a result of computers eliminating secretarial functions or making it more practical for managers and professionals to perform tasks directly on their own computers, as opposed to business efforts to rein in personnel costs. In the end, the processes may be inextricably intertwined and the distinction may be academic given the way the former facilitates the latter.

Computer-Aided Design

The final area of office work in which the effects of computers has been studied in detail is the effect of computer-aided design (CAD) on engineering and architectural drafting. CAD software originated in the 1960s but became particularly widespread beginning in the 1980s. CAD programs allow engineers, architects, drafters, graphic designers, and their assistants to draw and revise plans and blueprints as often as necessary, manipulate lines and shapes easily, automatically calculate and recalculate

[2] Assuming a 7-hour workday, the prediction implies total productivity gains of 7/3=2.33 over 23 years. This implies an annual productivity growth rate of $[(2.33^{1/23})-1] * 100 = 3.75$.

dimensions, and modify previous, archived designs for new situations. CAD software also makes it possible to print drawings as often as necessary, eliminating the need for copying or redrawing labor. In addition, CAD allows designers to simulate different scenarios on the computer, which eliminates the need for time-consuming physical prototypes or testing in many cases. CAD systems can also construct lists of required parts and materials for jobs for production planning purposes, revising them automatically as the design is altered (Liker, Fleischer, Arnsdorf 1992; Giertz 1987, p.9).

As a building block of a more fully automated factory, manufacturing CAD systems can be linked to computer-aided manufacturing (CAM) software that controls machine tools or other mechanical equipment, which can then execute CAD designs automatically. CAD/CAM also creates a computer database of designs for future use. As with NC/CNC, this has the potential to reduce skill requirements among skilled trades workers. However, in practice, problems with the CAD-generated instructions—due to a factory's environmental conditions, idiosyncrasies of specific machines, or problems with the CAD-generated programming instructions themselves—often require human intervention by skilled workers at the point of production.

Among drafters, the simplest use of CAD programs is as an electronic drawing board that allows the user to revise two-dimensional drawings more easily and rapidly and reproduce repetitive material, similar to the way writers use a word processor. CAD drawings are also more precise and can represent greater design complexity than most manual techniques. More complex functions involve modeling three-dimensional objects, including identifying relationships and any inconsistencies between different parts of an overall design, many of which are drawn by other members of a large project team (McLoughlin 1990, pp.221f.).

CAD's potential productivity advantages, then, include: greater speed, accuracy, and convenience in drawing objects and performing calculations; and the ability to visualize and simulate three-dimensional objects, construct more complex designs, and improve information flow between different designers and between designers and manufacturing or construction processes, including customers and suppliers at other firms (McLoughlin 1990, p.222; Liker et al. 1992, p.74; Giordano 1992, p.110). The most extreme predictions in the early 1980s were that CAD might eliminate drafters by 2000, but the U.S. Department of Labor's Bureau of Labor Statistics correctly predicted that the number of drafters would actually increase (cited in Attewell 1992, p.75).

The question is whether CAD affects occupational skill requirements or the occupational composition of the design and drafting work force to any appreciable degree. One clue is the rising perception by the 1990s that previous predictions of productivity gains from CAD were vastly overstated and a growing awareness that high-level program features were underutilized significantly (Liker et al. 1992; Harris 1994).

One study of CAD use in the early 1980s in five British firms (manufacturing, shipbuilding, construction, engineering services) found the jobs that were affected required fewer manual drawing skills than previously. However, the programs may require more abstract reasoning skills and allow some design functions previously performed by architects to be delegated to drafters. The greater integration of processes across department also meant that members of the drawing office had to have a broader understanding of the complete process than previously so that they understood the implications of their actions for other users (McLoughlin 1990, pp.223f.).

However, this was counterbalanced by the fact that many firms had dedicated CAD operators who performed routine work involving the production or alteration of standardized drawings, sometimes working in central offices like the word processing typing pools criticized in the deskilling literature. In other cases, professionals, rather than dedicated CAD operators, used the programs. However, even in these cases, there was often extensive underutilization of the more advanced software capabilities due to a lack of management commitment and training. Consequently, CAD was often used for routine drafting activities (McLoughlin 1990, pp.226ff.).

A study of six American manufacturing firms in the Fortune 100 produced similar results. In 1988 Liker, Fleischer, and Arnsdorf (1992) surveyed designers and design engineers (n=243) and interviewed managers, engineers, and drafters (n=77) at ten sites in six firms (aerospace, autos, consumer products). They found that few firms used CAD for more than two-dimensional drafting, "drawings that were essentially electronic rendering of blueprints" (Liker et al. 1992, p.77). Most of these companies simply replaced drawing boards with CAD systems. The major exception was the use of CAD to construct wireframe models, but more complex models of surfaces and solids were rare, in part due to the complexity of representing 3-D shapes on the screen.

In addition, most designers created new parts without borrowing from archived designs. Most designers found that contributing to the creation of design libraries was too time-consuming, but this limited the productivity gains from reusing routine parts of designs (Liker et al. 1992, p.77). Work processes remained segmented across traditional boundaries. Design and manufacturing remained isolated from one another and, at one firm, CAM data were entered into the computer by hand from blueprints. The authors found few true examples of integrated CAD/CAM, and suppliers for many companies did not have the technology or compatible systems to access the contractors' CAD databases (Liker et al. 1992, pp.79ff.). In many cases, the most advanced CAD features were simply not necessary for the design task (Liker et al. 1992, pp.82ff.).

These studies suggest that CAD is unlikely to affect skill demands greatly, whether through changes in the occupational distribution or changes in the skill content of existing jobs. Improvements in design efficiency do not seem to be so great that many drafters will be displaced, and the use of advanced CAD features seems too limited to greatly affect skill requirements within drafting or design engineering jobs.

However, there are somewhat contrasting cases. Giordano's study (1992) of a defense contractor found that CAD eliminated manual drafting skills and simplified some of the other skills that were traditional tickets for drafters to be promoted to more complex design work. However, CAD also required the ability to think more abstractly (Giordano 1992, pp.124f.).

A study of an engineering design department of a large American aerospace company in the mid-1980s found that designers estimated they needed 9.4 months of formal training and learning-by-doing to reach an adequate level of proficiency on the CAD system. However, only half of the 1,500 designers employed by the company used CAD frequently in their work. The study also cited other research that found training times for designers only half as long as for this company (Harris 1994, p.247).

It is possible that recent developments have made CAD software easier to learn because the interface is more user-friendly or have made it more challenging by adding more complex functions, but this review did not uncover research dealing with these questions.

CHAPTER 4: RETAIL

A final area that is much less studied is the impact of IT on retail employment. Despite rapid diffusion of bar code scanners and point of sale terminals in grocery stores, the percentage of industry employees who were cashiers rose modestly between 1983 and 1993, while the relative number of managers declined (Moody 1997, pp.13,23; Handel 2000).

An emerging area of particular interest is electronic commerce. E-commerce has been defined as including the use of a computer network or the internet to order, bill, and pay for goods and services, share databases across organizations, manage inventory, transfer funds, update records, satisfy customer inquiries, and provide other information (Hecker 2001).

Hecker's (2001) impressionistic survey is one of the few papers to address the employment impacts of e-commerce. However, the article generally describes possible future developments, rather than actual impacts, because e-commerce is still too small to have much impact. Hecker believes that e-commerce will dampen growth in a range of lower-level white-collar office occupations, such as bookkeepers, purchasing and warehouse personnel, clerks, travel agents, bank tellers, retail sales workers, and postal clerks. This reflects two characteristics of e-commerce: it is a higher level of office automation, and it transforms more transactions into self-service. Most of the jobs affected are relatively less skilled. For example, Hecker is less confident about any negative impacts of distance learning on employment in educational institutions. However, other more-skilled occupations, such as stockbrokers and insurance agents, may also face employment declines because the use of the internet facilitates self-service (Hecker 2001, p.13).

CHAPTER 5: CONCLUSIONS

Case studies, by their nature, do not involve representative samples, often do not collect standardized information, and tend to produce diverse conclusions. Consequently, they are difficult to use as a basis for generalization. However, they also study particular situations in greater detail than survey data and produce rich information about which many survey studies can only speculate.

Not all of the evidence from the studies in this review points in the same direction. Nevertheless, some tentative conclusions are possible. It seems safe to say that extreme views regarding job displacement, skill upgrading, and deskilling are mistaken. The effect of IT on employment levels, occupational composition, skill requirements within jobs, and wages are more modest than either proponents of the skill-biased technological change or deskilling theories believe. It does seem that technological change works mostly in the direction of skill upgrading, but the magnitude of these effects is unclear and may be gradual enough that their impacts are easily absorbed. There is little compelling evidence on the face of it that would support the idea that information technology has been a significant source of increased U.S. wage inequality.

Nevertheless, fuller understanding of this issue requires the collection of more standardized data on employment and wage implications of new technology. If further progress is to be made on these questions, representative surveys, sectoral studies, and case studies should investigate more systematically, as an explicit part of their research design, precisely how IT affects industry employment, occupational composition, skills within jobs, and wages.

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