Chapter 1

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OVERVIEW

Programmable automation technologies are attracting attention as outgrowths of the evolution of computer and communications technologies and as instruments of potentially far-reaching change in the operations, structure, competitiveness, and hiring patterns of many industries, particularly in manufacturing. While popular recognition of programmable automation seems to be confined mostly to one of its forms (robotics), programmable automation comprises other types of hardware, software, and systems. * The family of programmable automation technologies, as applied in manufacturing, is the subject of an Office of Technology Assessment (OTA) study, "Computerized Factory Automation: Employment, Education, and the Workplace, " which is scheduled to be completed in late *1983.* This technical memorandum, which is an interim product of that assessment, presents a set of concepts and background materials that are fundamental to the analysis of the labor and education and training implications of programmable automation technology.

The OTA assessment is examining the development and production of programmable automation technologies and their use in discrete product fabrication and assembly. It is examining the application of programmable automation to the entire manufacturing process, from design through production. The assessment is concerned in part with the economic and social aspects of the production and use of programmable automation, including:

- impacts on the types and mix of products manufactured,
- the structure and competitive behavior of manufacturing industries,
- the numbers and skill mix of people employed in manufacturing, working conditions in manufacturing jobs, and
- the education and training requirements implied by growth in the production and use of programmable automation.

Although it addresses the potential of programmable automation for the manufacturing sector as a whole, the assessment highlights implications for the transportation equipment, industrial machinery, and electronics industries, where the greatest impacts may occur in the next 10 to *15 years.*

Early work on this assessment revealed that analysis of employment change depends critically on methodology, while analysis of instructional requirements demands appreciation of the existing nature of, and delivery system for, education and training. These fundamental issues are the subjects of this technical memorandum. The remainder of this introduction provides a brief review of the evolution of programmable automation and sets out several factors that influence the social and economic consequences of new technologies. The labor chapter (ch. 2) discusses methodology and provides background material useful for evaluating employment and working environment changes. It draws on the products of a workshop held by OTA in July 1982, where questions concerning the analysis of labor markets and industrial relations were debated. The education and training chapter (ch. 3) examines the current status of education and training provided by schools, labor, industry, and others to persons holding or aiming to hold jobs in manufacturing industries. It draws on the results of an August *1982* survey conducted by an OTA contractor.

*Besides robotics, programmable automation includes computer-aided design (CAD) and manufacturing (CAM), computer-aided process planning (CAPP), automated materials handling (AMH), and automated storage and retrieval systems (AS/RS).

'*Exploratory Workshop on the Social Impacts of Robotics—A Background Paper* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, February 1982), OTA-BP-CIT-11.

PROGRAMMABLE AUTOMATION TECHNOLOGIES

Programmable automation may be viewed as the latest development in a long process of enhancing and augmenting human labor with various devices. Throughout history, people have combined human effort and skill directly with the cutting and shaping abilities of tools. With the development of machines, people drew on mechanical and other external sources of power, reducing the amount of human effort, and to some extent skill, needed for production. Automation, in turn, represents an advance over simple machines consisting of a transfer of skills and efforts for operating and controlling equipment and systems from people to machines. Conventional automation has improved production efficiency where automated machinery has been tailored to specific applications and devoted to the production of single products produced in large quantities. Programmable automation, which weds computer and data-communications capabilities to conventional machine abilities, increases the amount of process control possible by machines and makes possible the use of single pieces of equipment and systems for multiple applications. This flexibility may make programmable automation more economical than conventional automation across a range of applications from large volume production to production of small batches of products. Consequently, differences between large-scale, batch, and even custom production techniques may diminish and traditional ways of thinking about manufacturing may ultimately change.

Programmable automation technologies are not new, at least in concept; they have been introduced and refined over the past two to three decades. Many date the launch of programmable automation to the mid-1950's, when numerical control (NC) for machine tools (currently considered as part of computer-aided manufacturing) was developed and commercialized. The intervening years have seen growth in the capabilities and use of NC, the introduction of industrial robotics in the 1960's, and the initial applications of computer technology to manufacturing design, production, planning, and analysis in the 1960's and 1970's. During this period, capabilities and applications for programmable automation have grown, while associated unit costs—at least for the computer aspects—have declined.[2] The technologies and their potential markets appear to have developed sufficiently to lead many manufacturing industry analysts to anticipate substantial growth in the production and use of programmable automation in the 1980's and 1990's. However, current use of programmable automation is limited. For example, while the Robot Institute of America reports that less than 5,000 robots were believed to be in use in the United States in 1981, the National Machine Tool Builders' Association reports that over 2.6 million machine tools were in use in U.S. metalworking industries alone by the late *1970's*.[3,4]

At this time it is possible to identify four attributes of programmable automation, as compared with conventional automation, that may have major ramifications for labor and for education and training:

- capacity for information processing as well as physical work, in connection with such processes as planning, routing, design, fabrication, assembly, monitoring, and diagnosing process problems;
- capacity for quality enhancement, through reliability, precision, and adaptive control of the production process;
- capacity for application to the production of a diverse mix of products, through reprogrammability; and
- capacity for integrating production equipment and systems with each other and with design, analysis, inventory, and other aspects of the manufacturing process.

These attributes will influence: 1) the types and the range of human skills and other abilities that can be replaced by machines, 2) the types of new

[2] "SME Golden Anniversary Issue, 1932-1982: A Review of Manufacturing and the Society Which Guides Its Progress," *Manufacturing Engineering*, January 1982.

[3] *Worldwide Robotics Survey and Directory* (Dearborn, Mich.: Robot Institute of America, 1982).

[4] *Economic Handbook of the Machine Tool Industry* (McLean, Va.: National Machine Tool Builders Association, 1982-83).

applications within which both men and machines can be combined, 3) the types of skills required to produce programmable automation, 4) the types of products (existing and new) for which programmable automation may be used, 5) the costs of producing given quantities of different products, and 6) the organization and management of the manufacturing process. Consequently, they may give rise to changes in the numbers and types of people employed, and therefore changes in requirements for education, training, and retraining. Distinctive attributes of programmable automation will also influence the working environment of people employed in manufacturing. How much, an-d in what ways employment patterns and working environments change will depend on how automated equipment and systems are designed and implemented.

Conventional automation and other types of manufacturing technologies have traditionally affected—both positively and negatively—the employment and working environment of manual workers. Because of its capacities for performing information processing work and for integrating the manufacturing process, programmable automation may also have significant impact on other types of workers, the so-called white- and gray-collar workers, including managers.

DIMENSIONS OF TECHNOLOGICAL CHANGE

It is possible to relate the emerging capabilities of programmable automation technologies to changes in employment, and therefore education and training requirements, in the abstract. However, the effects of programmable automation on labor overall, as well as the experiences of specific groups of people, depend on how programmable automation technologies are implemented. The development and implementation of programmable automation, or other new technologies, can be appraised according to three factors: 1) the rate of technological change, 2) the nature of the change, and 3) the pattern of technological diffusion associated with programmable automation. These factors, which reflect a combination of technological and industrial/economic factors, are central to assessments of the social and economic impacts of new technology. They are reviewed briefly below.

Rate of Technological Change

There are two components to the rate of technological change, the rate at which new technologies are created and the rate at which they are adopted by users. For appraising the impacts of technology on employment and related education and training needs, the rate of adoption is key; it determines whether changes in requirements for different types of labor affect primarily existing or future/prospective employees. Although new technologies may be created at varying rates, the conventional view among economists is that the use of new technologies spreads relatively slowly. It is commonly assumed that firms adopt new technology in a rational fashion, meaning that they strive to use the most affordable processes to avoid the costs of prematurely scrapping facilities and to adapt technologies to their individual needs. This view implies that, since firms typically do not adopt each technological advance as soon as it is developed and since firms experience some normal level of employee turnover, employees are not (repeatedly) subject to catastrophic displacement. A more elaborate presentation of this view and a discussion of supporting research can be found in a paper by L. Jacobson and R. Levy, appendix C.

Although the notion that there is a lag between the introduction of a new technology and its widespread use is commonly recognized, there is disagreement as to whether recent innovations based on microelectronics technology have or will continue to spread as slowly as previous ones. For example, innovation and associated employment change in the printing industry have proceeded quicker than the conventional view might lead one to expect.

> In West Germany, for example, employment among printers dropped by 21.3 percent between 1970 and 1977, while productivity per hour rose by 43.5 percent . . . .[5]

There is also evidence that the use of computers has spread relatively rapidly, a phenomenon that has prompted many scientists and engineers to take steps to refine their skills. A discussion of technological diffusion and its impacts on scientists and engineers is found in a paper by W. Cooke, appendix C. Additional material on engineering education is presented in chapter 3 of this technical memorandum.

A central question for an analysis of the social and economic impacts of programmable automation is whether programmable automation is likely to spread especially rapidly among firms and industries, and why. Answering that question requires appraising the influence of the international nature of markets producing and using programmable automation and the influence of cyclical and structural change in the U.S. economy on the rates of adoption and production of programmable automation in the United States.

Nature of Technological Change

The way in which technological change affects employment and instructional requirements depends on the nature of the technology. The aspects of the technology that are relevant to an examination of labor impacts fall into three categories:

1. process v. product technology,
2. embodied v. disembodied technology, and
3. capital intensity of technology.

Process technologies are technologies of production, while product technologies pertain to the attributes of a finished product. Programmable automation, which comprises a set of goods and services used by businesses to make other products, has elements of both, but is primarily regarded as process technology.

The product-process distinction is important because, historically, process changes have been more likely to affect employment adversely than have product changes. New products (such as programmable automation equipment and systems) create new markets and new sources of employment (although net employment growth depends on whether—and when—new products replace older ones). New processes, however, are often adopted because they are considered efficient, using fewer resources than older processes to yield a product of given quality. * If the conserved resource is labor, a company adopting a more efficient process will need fewer employees for a fixed output level. If the company faces a mature market for its end product (i.e., sales volume is not likely to grow significantly), overall employment will fall, but, if the company faces a growing market, it might experience stable or growing employment. Also, some new processes may be adopted to improve product quality without necessarily diminishing company employment. Discussions of programmable automation in the trade and business press typically note its potential for both efficiency and quality enhancement. These discussions, which separate quality gains from cost reductions, recognize that process improvements may facilitate output growth but do not assure that companies can sell larger volumes of output.

Embodied technologies are associated with physical entities such as pieces of equipment. For example, mechanical adding machines and electronic calculators embody different technologies to perform the same functions. Disembodied (sometimes called soft) technologies constitute ways of organizing and managing production that are not locked into tangible items. An example is the just-in-time system of inventory management, wherein suppliers deliver materials for virtually immediate use (rather than interim storage). The contrast between embodied and disembodied technologies is important for appraisal of programmable automation because the spread and the ultimate utility of programmable automation is linked to associated changes in the organization of production and the structure of companies and industries.

In evaluating embodied technologies used in manufacturing and elsewhere, it is important to

'Cohn Norman, *Microelectronics at Work: Productivity and Jobs in the World* Economy, Worldwatch Paper 39, October 1980.

● Sometimes this characteristic is referred to as productivity improvement, since productivity refers to the amount of output derived per unit of input to production.

recognize that disembodied technologies can often complement or even substitute for them. For this reason, comparing counts of different types of equipment (e.g., robots) used by different countries may be misleading. As comparisons of automobile production in the United States and abroad reveal, it is possible to produce the same product using equipment and systems that differ in sophistication under different principles of organization and management. Also, because embodied and disembodied technologies are combined in production, simple attributions of employment or working environment variations to changes in equipment and systems are hazardous; they ignore the role of management, organization of production, and other "soft" factors.

Capital intensity refers to the amount of investment in plant and equipment needed to produce a given level of capacity, relative to the amount of other inputs, such as labor. A capital-using change in technology is defined to be one that requires more investment to produce a unit of product than the original technology; a capital-saving change, one that requires less investment; and a capital-neutral change, one that requires the same investment per unit of product.

Generalizations about how programmable automation may affect capital intensity in different manufacturing applications are difficult to make at this time because of limited experience with the technologies and uncertainty about the evolution of the technologies and their markets. However, an understanding of the capital intensity aspects of programmable automation is important for understanding the long-term employment and wage impacts of programmable automation. In brief, capital intensity affects the flexibility employers have for accommodating different employment and wage levels, given company levels of sales volume and of output per worker. * The ramifications of varying levels of capital intensity are examined in a paper by E. Appelbaum, appendix C.

*Capital intensity may *also* affect the distribution of wealth generated through production—a shift to capital-using technologies may, for example, be associated with growth in profits (return on capital) relative to wages. Changes in the distribution of wealth in turn may affect employment and wage levels because those realizing income as profits may spend and invest in different markets than those realizing income as wages.

Pattern of Technology Diffusion

The impacts of programmable automation technologies will depend on where they are used as well as when. New technologies may spread within industries among all firms, among firms in only certain industry segments, or among large or leading firms only. They may be used in isolated industries, interdependent industries, and/or in industries in different sectors of the economy. The impact of programmable automation technologies on employment (and therefore on instructional requirements) in the United States will depend, in particular, on global trends in the production and use of programmable automation, since the markets for automation and for many products made with it are international.

Preliminary observations presented by industry and labor representatives and technology analysts at the 1981 OTA Exploratory Workshop on the Social Impacts of Robotics and elsewhere indicate that programmable automation may eventually be diffused more broadly than conventional automation.[6] While conventional automation has been applied primarily in large-volume or mass-production manufacturing industries, programmable automation offers potential value to use in smaller volume, batch manufacturing applications, which are the majority of manufacturing applications.[7] Whereas conventional automation is devoted to production of single products, programmable automation equipment and systems can be adapted, through reprograming, for production of multiple products, each of which may be desired in limited quantities. Since production equipment and systems themselves are often manufactured in small-quantity batches, their manufacture may be automated.

Finally, equipment and systems similar (and in some cases identical) to those used for programmable automation in manufacturing are being adopted in nonmanufacturing settings, with multiple impacts on employment opportunities. A possible consequence of the spread of office automation, for example, is a decline in the growth rate of clerical employment. On the other hand, large

[6] *Exploratory Workshop on the Social Impacts of Robotics-A Background Paper,* op. cit.
[7] Ibid.

investments in office automation equipment and systems imply potential employment gains in manufacturing industries supplying office automation, although who benefits from such employment gains depends on the extent to which office automation equipment is imported. The implications of the pattern of technology diffusion for employment in different sectors of the economy are discussed in a paper by E. Appelbaum, appendix C.