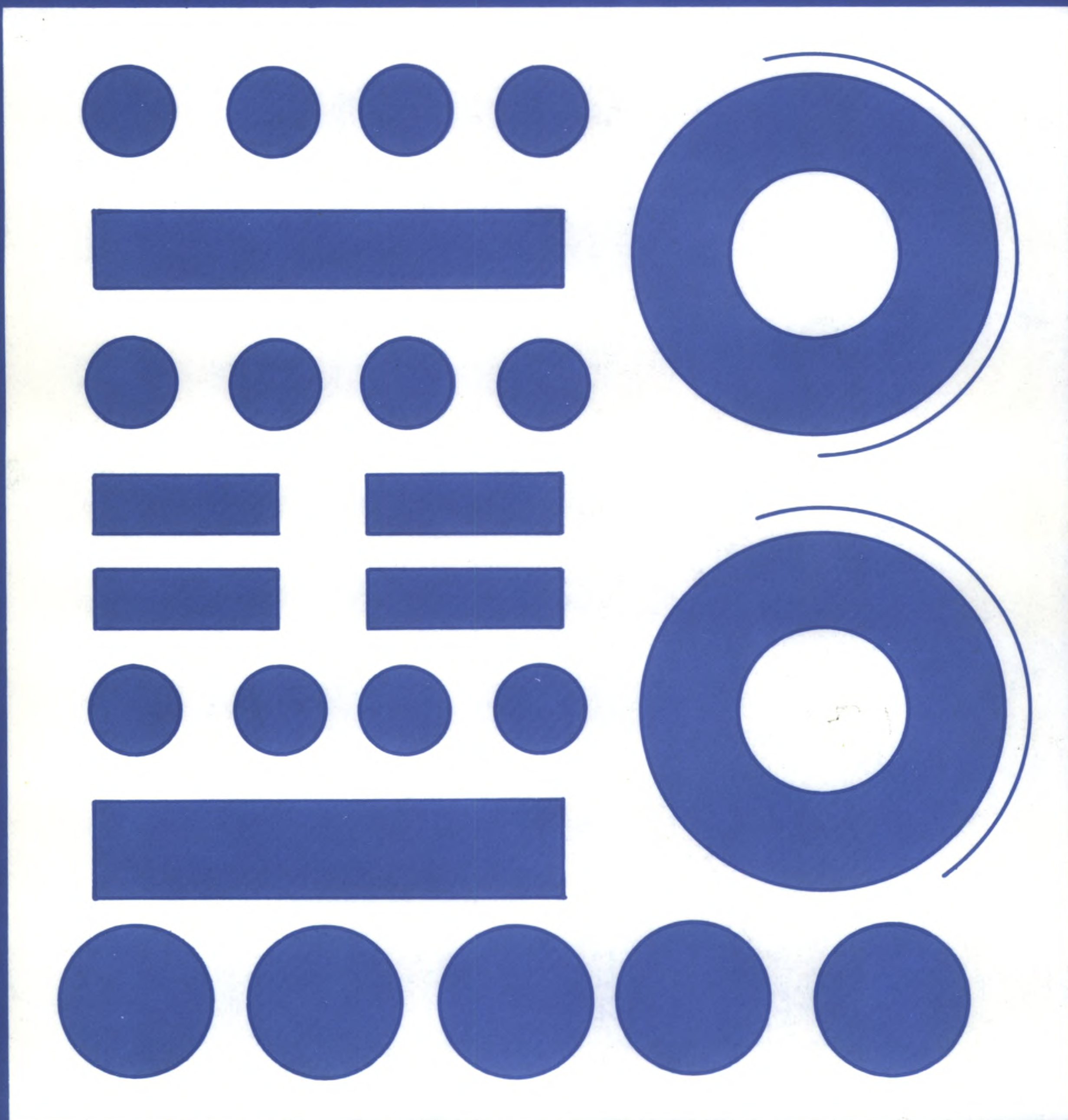
OUTLOOK for COMPUTER PROCESS CONTROL

Bulletin 1658

U.S. DEPARTMENT OF LABOR
Bureau of Labor Statistics



OUTLOOK for COMPUTER PROCESS CONTROL:

Manpower Implications in Process Industries

Bulletin 1658

U.S. DEPARTMENT OF LABOR
George P. Shultz, Secretary

BUREAU OF LABOR STATISTICS
Geoffrey H. Moore, Commissioner

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PREFACE

The Manpower Development and Training Act of 1962 directs the Secretary of Labor to establish techniques and methods for detecting in advance the potential manpower effect of automation, technological change, and other innovations that may result in changes in the structure of production. This type of early warning system could be of great assistance to management and union leaders, educators, government officials, economists, and others in planning policies to cushion the effects of change.

This bulletin focuses on effects of computer control of production processes. The number of installations of process computers is expected to increase substantially over the next decade, and this trend will have significant implications for productivity, occupational requirements, training programs, employment, and industrial relations in many major industries.

This study is one of a series prepared by the Bureau of Labor Statistics on technological developments and their effect in different industries. Our earlier studies include a survey on the use of computers for business data processing in government and industry, and a study that focused on the manpower implications of numerical control of machine tools in the metalworking industries. This bulletin provides firsthand information on manpower and economic implications of computer process control through study of applications in user plants.

The study focuses mainly on the effect of computer process control on employment, occupations, skills, training, and labor-management relations. Emphasis also is placed on the outlook for the future of this important innovation, the extent of its utilization by industry, and its impact on production and productivity. An account of the procedures that some companies used in planning and effecting changes may suggest to management and employee organizations measures that might be useful elsewhere.

The primary source of information presented in this study is data collected by BLS representatives during field visits to plants with significant applications of computer control. Additional information was obtained from discussions with union and government officials and experts employed by major manufacturers of computers and related equipment, and by reviewing secondary source materials, particularly trade and technical journals. The Bureau of Labor Statistics is grateful to the many individuals who provided useful information and reviewed the draft of this report. We also wish to thank American Cement Corporation, American Electric Power Service Corporation, American Oil Company, Bethlehem Steel Corporation, F.L. Smidth and Company, General Electric Company, International Business Machines Corporation, National Steel Corporation, and Westinghouse Electric Corporation for providing us with photographs.

This bulletin was prepared by Arthur Herman and Robert Ball assisted by Richard Lyon, under the direct supervision of Richard Riche. The study was made in the Office of Productivity, Technology, and Growth under the general direction of John J. Macut, Chief of the Division of Technological Studies. The report is part of the Bureau's research program on productivity and technological developments.

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CHAPTER 1. INTRODUCTION

One of the most significant technological developments in U.S. industry has been the introduction of electronic computers. Their phenomenal speed, remarkable versatility, and large storage capacity have transformed dramatically data processing operations in offices, banks, research laboratories, engineering firms, and other organizations, and have had widespread manpower effects. Although much research has been conducted into the employment effects of computers on office employees, relatively little is known about these effects on blue-collar and technical workers in factories and plants where computers now are being introduced to control production processes.

In an effort to assess the manpower impact of this emerging technology, this study undertakes to provide answers to the following questions: How extensively are process computers being used, and how many will be installed in the future? What factors, such as costs and benefits, govern the rate of adoption? What type of manpower is required to implement computer process control? How has employment been affected by this innovation? What changes in occupational requirements are brought about? What are the training needs for computer process control? What industrial relations problems arise?

This bulletin deals with the use of the computer as part of the operations of 12 plants in 6 process industries: electric power, industrial chemicals, steel, petroleum refining, paper, and cement.[1] Plants in these industries depend upon the monitoring of instrumentation and control devices to maintain process operations within precise limits. The computer represents a significant advance over conventional control devices since it can receive and store information about process conditions, perform calculations on this information to see if process conditions should be changed, and send out signals to process control equipment to make corrections when necessary.

The application of computers to industrial process control is growing rapidly in number and complexity. In many early installations, process computers were used primarily to accumulate and print out data on processing conditions, which assisted the operator to control the process using the same instrumentation and equipment as before. As experience broadened and technology improved, the operator increasingly was removed from direct involvement, and in the frequently used "closed-loop" mode of today, operators often only monitor process equipment while many control actions are taken automatically by the computer.

A significant segment of the Nation's work force is employed in process industries, which lead all other major industry groups in the application of process control computers. About 2 million workers, approximately 10 percent of the total work force in manufacturing, are employed in the six major process industries covered in this report. (See appendix B-1.) Thousands of employees in these industries work in production units with functions that have potential for computer control.

[1] Detailed information on scope and method is presented in appendix A.

CHAPTER 2. SUMMARY

Current use of process control computers is limited but outlook is for significant growth. By mid-1968, nearly 1,700 process control computers were installed or on order for a variety of applications in process and other industries throughout the United States. Process control computers were introduced first in industries with processes that require precise control over many variables, such as in petroleum refining, steel, chemicals, and electric power. Functions of process computers include collecting and recording operating data, providing information to guide operators in controlling the process, warning in case of impending equipment malfunctions, and undertaking automatic control of parts of the production process. Specific applications observed at survey plants included control of ammonia and ethylene processes in chemical plants; catalytic reforming and crude distillation units in petroleum refineries; electric generating equipment in electric power plants; basic oxygen and hot strip mill operations in steel mills; a papermaking machine in a paper mill; and a rotary kiln in a cement plant. Applications of process computers already have spread to many other areas, including automobile manufacturing, mining, research, and medicine. Advances in process computer technology, such as more reliable and greater capacity computers, specialized computer languages, and standardized programs and process models should accelerate computer use, with an estimated 5,900 installations in the United States forecast by 1975.

Adoption was encouraged by favorable cost benefit balance. The costs of introducing process computers were considerable, ranging from $200,000 to $1,500,000 at survey plants. Costs depended upon numerous factors including the complexity of the process to be controlled, the type of computer to be used, the amount of auxiliary equipment purchased, the amount of new instrumentation added, and the degree of control desired.

The major management objectives for installing computers were to decrease raw material and fuel costs and to optimize or increase production. A reduction in manpower requirements was a goal in only a few plants, since labor costs in operations to be placed under computer control at most survey plants were reported to be a relatively small part of total production costs.

Most plants achieved the gains that they anticipated, and benefits were substantial in some cases. Gains were achieved by reducing fuel and raw material costs, increasing output, producing products of higher dollar value, reducing equipment and process malfunctions, and decreasing labor costs.

Implementing computer process control required a substantial amount of technical manpower for a period generally exceeding 2 years. At survey plants, engineers, technicians, and supervisors from the plant staff were assigned to project groups for the purpose of applying computer process control. Working closely with this staff were systems analysts, programers, and technicians from the firm supplying the computer. In general, the plant installing the computer provided staff who were familiar with the process, while the firm manufacturing the computer supplied personnel experienced in computer operations, systems capabilities, and programing. This computer group worked on the following four major phases of implementing computer process control: Feasibility study; planning, systems design, model building, and programing; installation; and operational and system refinement. A range of from 2 to 21 man-years were required to complete computer projects at individual survey plants.

Impact upon plant employment has been slight, although job duties of employees working with computer control have been altered significantly. Employment levels at survey plants were affected more by factors other than computer process control, such as shifts in market demand, changes in general economic conditions, and adoption of other technological changes. Within computerized units, relatively little employment change occurred because most operating crews already were at a minimum consistent with the safe operation of the process. Although the computer assumed some of the manual tasks of the operators, the crew size was generally maintained at its previous level to cope with emergencies that might arise or possible computer failure. Consequently, no layoffs occurred and only 20 employess at 2 of the 12 plants visited were displaced because of changes attributed to the computers. All of the displaced employees who were available for work were reassigned to other jobs within their plants at no reduction in wages.

The most significant effect of the introduction of process computers was changes in job duties. A total of 352 workers, based on information from 11 survey plants, had their jobs modified. Operators in computerized units made up the largest occupational group affected. Job changes encompassed a shift from manual to automatic data logging and manipulation of dials, levers, and other control devices. Process operators generally were trained to operate the computer console and gained responsibility for the additional computer equipment installed in the control room.

Another occupational group significantly affected was instrument maintenance technicians. These employees generally were trained to service the additional process instrumentation needed for computer control and in some cases also were trained to provide normal service for the computer and auxiliary equipment.

The growing use of process computers probably will reinforce a number of divergent employment trends underway in the process industries. Employment of workers such as control and systems engineers, electronic and instrument technicians, and programers, is expected to increase. On the other hand, fewer operators may be needed.

Occupational structure generally was upgraded. A total of 68 new jobs were required to implement and operate process computer systems in survey plants. Systems analysis, programing, and related occupations made up about two-thirds of the new jobs; the other one-third consisted of supervisory, computer console operation, and instrument development, installation and maintenance occupations. Employees assigned to new computer-oriented jobs generally were upgraded in title and salary. Most of the new jobs were staffed by employees who already were working for the user firm in other positions and had a thorough knowledge of the process to be put under computer control.

A large majority of the employees selected for the new jobs were college graduates with a degree in engineering or a related field. A small number of new jobs, however, were staffed by personnel without college degrees. Particularly noteworthy were the upgrading of clerical workers and technicians to positions involving computer programing. A technical assistant at a petroleum refinery and a powerhouse fireman at a papermill, for example, received training and were advanced to computer programing positions with substantial increases in salary.

Fairly extensive training was needed to introduce and operate process control computers. A total of 638 survey plant employees, an average of 53 per plant including supervisors, engineers, programers, operators, and technicians, received classroom or on-the-job training. Computer manufacturers provided training both at the plant and at schools located elsewhere. This training, which consisted for the most part of formal classroom instruction in computer concepts and theory, and programing and maintenance techniques, was provided mainly to supervisors, process engineers, instrument engineers, and electronic and instrument technicians. The period of training depended greatly upon the type of instruction provided; the average time was almost 5 weeks per employee and ranged from a 4 hour onsite orientation session in computer basics and system usage, given to dispatchers in a steel plant, to a 1-year course combining onsite and offsite training in programing and computer technology provided to a programing maintenance technician in a chemical plant.

Process operators in computerized units received relatively short periods of onsite instruction, generally from plant engineers and supervisors. The training period for operators ranged from 4 to 120 hours; about two-thirds received 20 hours or less of formal training. Operator training consisted mainly of on-the-job sessions dealing with the operation of the computerized equipment, although some classroom training was given at a few plants. A small number of instrument maintenance technicians also received short periods of onsite training provided by user personnel.

The selection of persons to be trained for the new computer-related programing and maintenance jobs most often was determined by an individual's educational background, work experience, job performance, aptitude, and interest. Tests and interviews sometimes were used as a screening device. On the other hand, operators and supervisors working in the affected production unit when the computer was installed automatically received appropriate training.

Process computers were introduced in survey plants with a minimum of industrial relations problems. Special union-management negotiations or grievances related to the introduction of process computers were reported at only two plants. At a petroleum refinery, a union negotiated for jurisdiction over all computer maintenance and gained jurisdiction for repair of minor difficulties. At a power plant, a union unsuccessfully filed grievances about the normal abolition of two extra operator's jobs, claiming that operation of the computerized unit was unsafe without the extra workers.

Workers were represented by unions at 9 of the 12 plants. Collective bargaining agreements at survey plants generally contained provisions which protected workers against the adverse affects of technological change. These provisions covered advance notice to employees, procedures for staffing new jobs, establishment of wage rates, eligibility for training, and procedures for layoffs, downgrading, and transfers.

Formal advance notice of impending installation of process computers was provided at most plants from 4 months to 2 years in advance of installation during meetings between company and union officials. In addition, employees learned about these pending changes through articles published in company newspapers and announcements placed on bulletin boards.

In general, local union officials interviewed felt that the introduction of process computers was part of the normal technological evolution in their industry and indicated that workers faced no serious problems in their adaption to computer control. Some officials were more concerned with the manpower impacts of technological changes other than computers. However, several union representatives foresaw that the potential of computers for adverse manpower effects would increase as the level and scope of their control is extended.

CHAPTER 3. ROLE OF THE COMPUTER IN PROCESS CONTROL

The electronic digital computer is the culmination of a series of major developments in process control allowing more automatic control of many different types of production processes. This chapter discusses the characteristics of computer process control and describes some of its technical forms.

Characteristics of Computer Control Systems

The adoption of electronic digital computers for process control is part of the evolutionary trend toward more continuous processing and less dependence on manual control in the process industries.

Prior to the introduction of the digital computer, equipment such as automatic controllers—which automatically make adjustments to keep process variables near preset values; automatic data loggers—which are connected directly to the process to provide a permanent record of operating conditions; and analog computers—which provide automatic control over a limited number of process variables, were in widespread use in the process industries.

As processes became more complex and instruments more numerous, operators frequently were inundated with large volumes of information. The number of instruments, the complexity of variable interactions, process time lags, and the short time allotted for analysis and decision making made it extremely difficult, even with analog computers and advanced intrumentation, to incorporate all the available information into accurate and consistent control decisions. These problems, in addition to anticipated economic gains, led to the application of digital computers to industrial processes.

One eminent authority summarizes the potential of electronic digital computers for process control in the following statement:

> Because of the key role of information in control. . . .the computer is a logical tool to be applied: the outstanding characteristic of a digital computer control system is the ability to acquire, assimilate, analyze, and disseminate large amounts of information with great speed, accuracy, and flexibility.[2]

Computers originally were developed for engineering and scientific calculations and later were adapted to business data processing and control functions. The development of industrial process control computers parallels that of scientific and business computers. Modern computers are in their "third generation;" the first used vacuum tubes, the second used transistors, and the third uses integrated circuits. Process control computers differ from business and scientific computers, however, in that they are smaller, less expensive, more rugged, and designed for trouble free operation under adverse conditions. Moreover, they are capable of receiving input directly from the process. They depend on a number of rapidly advancing technologies including electronics, data processing, control engineering, operations research, and systems engineering, and, therefore, require a great deal of advanced engineering and other skills for design, installation, programing, and maintenance.

Since 1958, when the first industrial control computer was introduced, the price and size of these machines have declined while their speed and reliability have increased. Recently, computer manufacturers introduced smaller and lower-priced models which increase the prospective number and type of control applications, since they can be used where large computers would be uneconomical.

In the most elementary control applications, the computer is not connected directly to the process and functions as an extension of instrumentation, collecting and recording data about the process which is entered manually and interpreted by the operator. In its more advanced functions, however, the control computer is connected directly to the process and is part of a total system of control. These advanced functions of computer control range from printing out explicit instructions for an operator to follow, to complete automatic control of the process.

Control computers are being applied to large sections of plants as well as unit operations such as catalytic cracking in petroleum refineries and hot strip mills in

[2] Emanuel S. Savas, *Computer Control of Industrial Processes* (New York: McGraw-Hill Book Company, 1965), p. 4.

steel plants. They may be used eventually in integrated, companywide control and information systems, in which economic decisionmaking as well as engineering factors would be considered in controlling production. When computers are linked together in a plantwide system of control, those computers at the top of this hierarchy determine the level of production of the computers controlling individual processes. They also coordinate many plant operations such as raw material requirements, maintenance of the size of inventory, scheduling of materials, future orders, and equipment capacity. For the first time, the problems of operating complicated and interrelated units and processes close to optimum production and integrating their operation with that of the entire plant can be resolved.

The components of a process control computer system indicated in chart 1 are basically the same as those of a business or scientific computer system: A memory unit in which data are stored; a control unit which directs computations and switching; an arithmetic unit which calculates; and input-output units which provide communication with the computer (such as typewriters, paper tape readers, manual keyboards, etc.). The control and arithmetic units sometimes are called the central processing unit.

Unlike a business and scientific computer system, however, a control computer system is connected directly to sensing devices which measure product qualities, raw material characteristics, temperatures, flows, pressures, and other process conditions. Various signal converters change the signals from these sensing devices into a digital form usable by the computer. Signals from the computer are often relayed through analog controllers to devices or positioners in the process. These control devices regulate the temperatures, flows, or other variables at the desired operating conditions. In another form of process control, called direct digital control (DDC), the analog controllers are omitted, and the computer is connected directly to the control devices or actuators.

The operator communicates with the computer through input-output equipment. He can supply information to the computer through pushbuttons, switches, knobs, typewriter keyboards, and punched paper tape or cards. The operator receives information from the computer by alarm buzzers, horns or lights, digital indicators, typewriter printouts, and video displays. However, he can bypass the computer entirely by taking direct readings from sensors and entering changes in the process through the analog controllers or by adjusting control devices manually.

1. Components of a process computer system, including main frame, disc memory, card punch and reader, printer, printout typewriters, and signal terminal cabinets.

Functions of the Computer

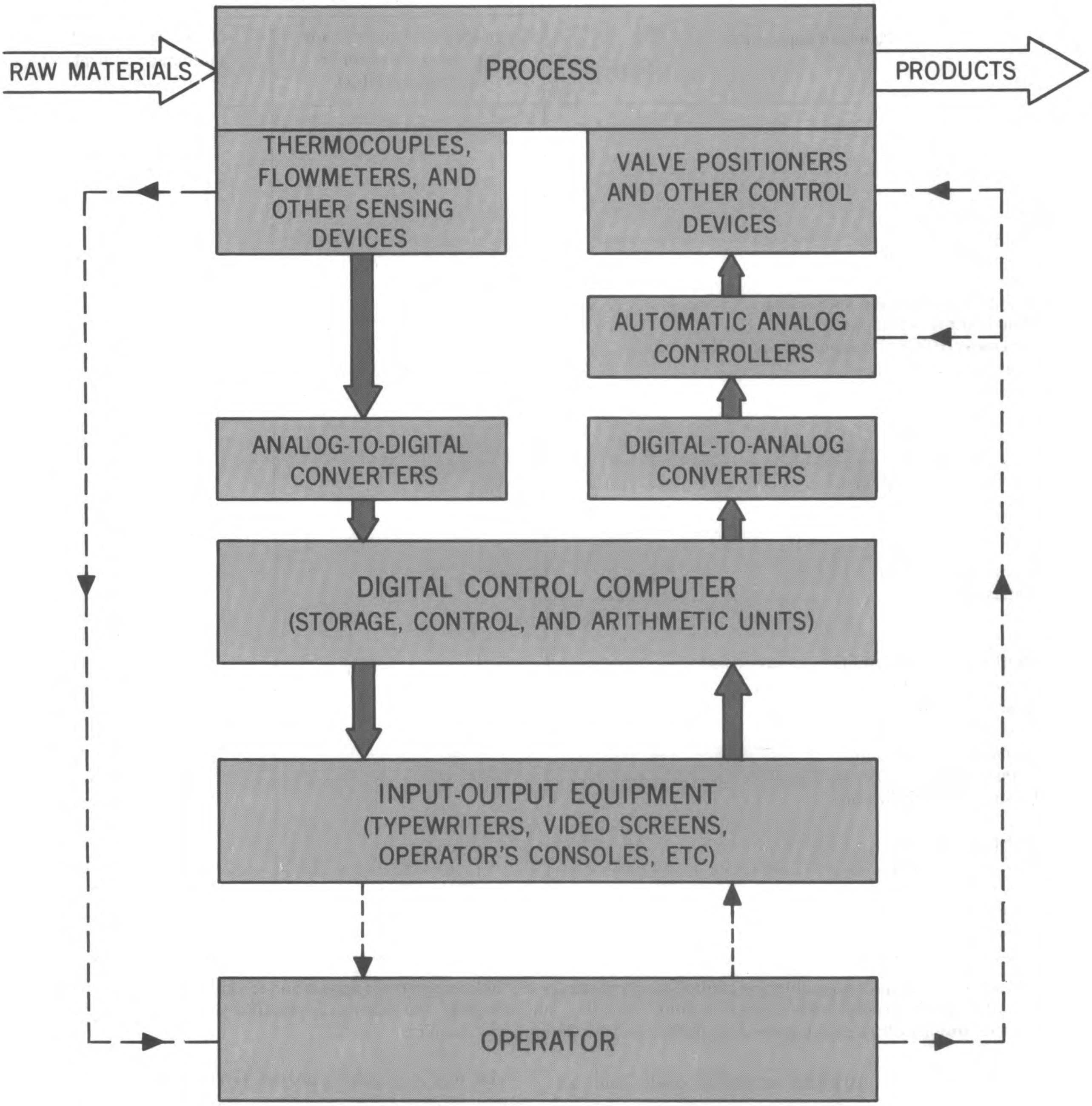
Of the 24 applications surveyed, 7 involved the simple form, called open-loop control, in which the computer monitors instruments, gathers data, makes calculations used by the operator in making control decisions, and activates audio or visual alarms in case of malfunctions. (See table 1.) Seventeen of the applications involved a more advanced form, referred to as closed-loop control, in which the computer calculates the exact control measures to be taken and performs the control automatically, in addition to performing open-loop functions.

To undertake these automatic closed-loop control functions, the computer is connected directly to process instruments; this procedure allows the computer to make control decisions and adjust controls automatically, thereby assuming some functions which previously were done by the operator. The interrelationship of the operator to the process and the computer in these two main categories of control is presented in chart 2.

Advanced Forms of Control

Optimizing control, used at all five survey chemical plants and petroleum refineries, is one of the most advanced forms of computer control. This form of control can incorporate the functions of a closed-loop

CHART 1. A DIGITAL COMPUTER CONTROL SYSTEM [1]



[1] ADAPTED FROM THOMAS M. STOUT, "MANPOWER IMPLICATIONS OF PROCESS CONTROL COMPUTERS IN THE PROCESS INDUSTRIES," THE OUTLOOK FOR TECHNOLOGICAL CHANGE AND EMPLOYMENT, VOL.1, TECHNOLOGY AND THE AMERICAN ECONOMY, THE NATIONAL COMMISSION ON TECHNOLOGY, AUTOMATION, AND ECONOMIC PROGRESS, FEBRUARY 1966, p. I-266.

NOTE: SOLID LINES INDICATE AUTOMATIC SIGNAL AND DATA TRANSMISSION; BROKEN LINES INDICATE MANUAL OPERATIONS.

Table 1. Level of control for computer applications in survey plants

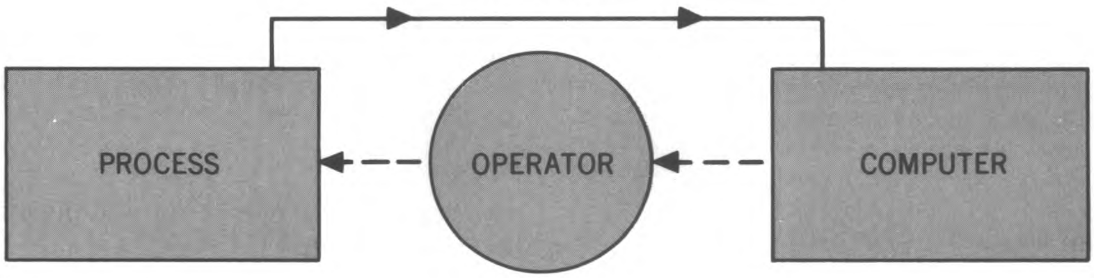
Plant and application	Highest level of control attained[1]	
	Open-loop control (monitor, log, calculate, alarm or instruct operator)	Closed-loop control (automatic control of variables)
Papermill:		
Paper machine		X
Chemical plants:		
Styrene plant	X	
Ethanolamine (DDC)		X
Corporate research laboratory		X
Multiplant production monitoring	X	
Plant control (4 computers)		X
Detergent (DDC) (2 computers)		X
Analytical laboratory	X	
Ammonia		X
Petroleum refineries:		
Crude distillation		X
Catalytic reforming		X
Polymerization		X
Catalytic cracking		X
Hydraulic cement plant:		
Rotary kiln		X
Steel mills:		
Multiplant fuel and utilities utilization and power prediction	X	
Basic oxygen furnace	X	
Hot strip mill		X
Tinning line		X
Tinning line		X
Continuous annealing line		X
Electric powerplants:		
Generating station	X	
Generating station	X	
Generating station		X
Generating station		X

[1] If one or more process variables are controlled automatically by the computer, the application is classified as a closed-loop system although the process is not necessarily fully controlled automatically. All systems so classified also perform functions such as monitoring instruments, logging data, performing calculations, and alarming.

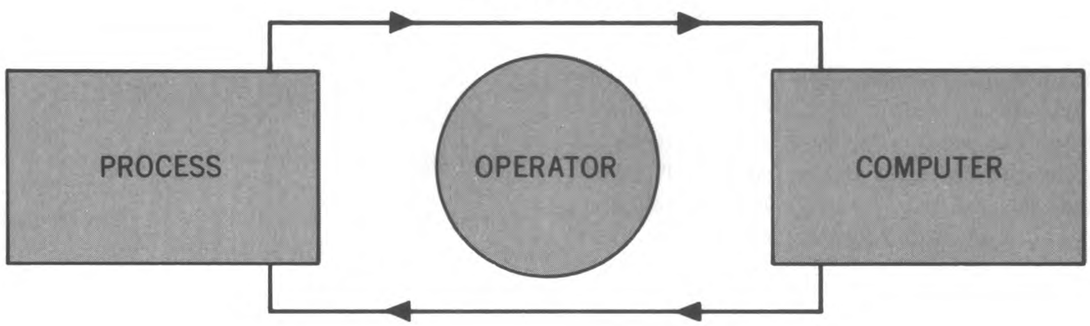
system while also controlling ultimate goals such as production costs, yields, or efficiencies. The objective is to achieve the best or most desirable operating conditions. The computer takes into consideration all significant variables, calculates the best process conditions, and applies the integrated control changes necessary to achieve the most desirable performance. This type of control is particularly appropriate for continuous processes in which many variables interact simultaneously. Optimizing control, for example, can be used to achieve the most profitable product mix from a given input of raw materials.

In direct digital control (DDC), another advanced form of computer control studied at two survey plants, analog controllers and other equipment used in conventional control are eliminated, and the computer itself receives instrument signals and produces control signals which are sent directly to the process. An advantage of this system is that, for some types of installations, the cost of the computer control system can be offset by the elimination of conventional instruments and control equipment. A disadvantage, however, is the difficulty in reverting to manual control in case of computer malfunction.

CHART 2. BASIC RELATIONSHIPS IN OPEN-LOOP AND CLOSED-LOOP CONTROL [1]



IN OPEN-LOOP CONTROL, THE COMPUTER RECEIVES INFORMATION ON PROCESS CONDITIONS DIRECTLY FROM PROCESS INSTRUMENTS. THE OPERATOR, HOWEVER, STILL INTERPRETS COMPUTER COMPUTATIONS AND UNDERTAKES CONTROL ACTIONS MANUALLY.



IN CLOSED-LOOP CONTROL, OPERATOR INTERVENTION THEORETICALLY IS ELIMINATED. THE COMPUTER RECEIVES INFORMATION DIRECTLY FROM THE PROCESS INSTRUMENTS, PERFORMS CALCULATIONS ON THE DATA, AND APPLIES THE RESULTING CONTROL DECISIONS AUTOMATICALLY THROUGH INSTRUMENTS TO PROCESS EQUIPMENT. HOWEVER, AN OPERATOR GENERALLY IS REQUIRED TO OVERSEE OPERATIONS AND TO MAKE SOME MANUAL ADJUSTMENTS, PARTICULARLY IN THE EVENT OF MALFUNCTIONS.

[1] ADAPTED FROM EMANUEL S. SAVAS, COMPUTER CONTROL OF INDUSTRIAL PROCESSES, NEW YORK: MCGRAW-HILL BOOK COMPANY, 1965, pp. 4-6.

NOTE: BROKEN LINES INDICATE MANUAL HANDLING OF INFORMATION; SOLID LINES AUTOMATIC TRANSMISSION.

CHAPTER 4. STATUS AND APPLICATIONS OF PROCESS COMPUTERS

Process computers have been introduced gradually, but the outlook is for their more widespread adoption. This chapter presents information on extent of use and trends in installation, and includes examples of applications in survey plants.

Extent of Use

As of July 1968, at least 1,674 digital process computers were reported installed or on order in the United States; this figure is based on information contained in trade journals, technical publications, and survey field visits. The number installed in the U.S. accounts for more than 50 percent of the world total. (See chart 3.) Installations counted encompass all applications of process control computers, including those outside of process industries, and those that are used for applications other than for control of a production process.

The electric power industry, a process industry included in the study, is the leading user of process control computers in the United States, with 292 installed in this industry as of July 1968. Next in importance among major categories of users, as indicated in table 2, is aerospace with 252 installations; followed by discrete manufacturing industries with 178; and research, medicine, and education with 166 process computers. Industrial chemicals and iron and steel, two process industries also included in the study, reported 156 and 132 installations, respectively.

Trends in Installation

The first on-line application of a digital process computer was at an electric power generating station in March 1958. This application, however, involved calculating station efficiency rather than actual process control. The first on-line process computer application to incorporate a control function became operational in March 1959 at a catalytic polymerization unit in a petroleum refinery. Since early process computer systems were experimental and very costly, relatively few were reported installed until about 1963. As information about the technology and advantages of computer process control and more reliable equipment became more widely available, the number of installations expanded rapidly. From September 1963 to July 1968, digital process computers reported installed or on order in the United States increased more than sevenfold.

Applications of Process Control Computers in Plants Surveyed

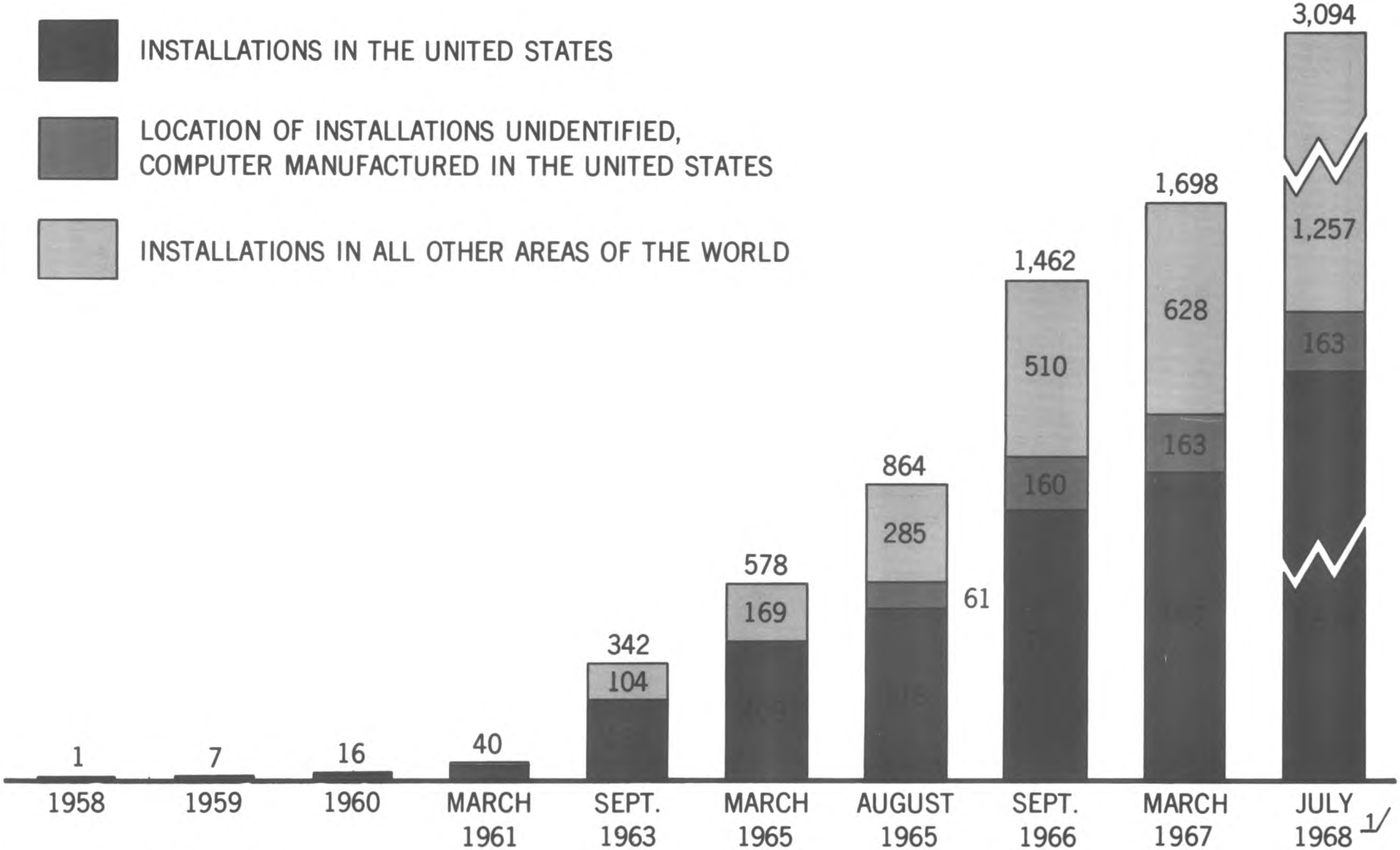
Electric power plants. All of the electric power plants visited for information were using process computers to assist in the operation of electric generating equipment. Computer functions included data logging, alarming, and equipment performance monitoring; these operations consisted of scanning numerous instrument readings, recording process information periodically, preparing performance reports, and alarming the operators when problems are sensed. (See table 3 for a list of applications in survey plants and appendix B-2 for distribution of computers by major applications in the six industries surveyed.)

At a survey electric power plant, for example, the computer logs all key variables and prints out a record of plant equipment performance, such as boiler efficiencies, heater and pump performance, and turbine operating ratios. The system is designed to discover malfunctions rapidly and can detect problems that, prior to computer control, might not have been observed until equipment failure.

Industrial chemical plants. A large chemical plant, whose major product is ethylene, uses a complex multicomputer system to provide operator guide control over almost all operations in the plant. The system monitors and collects data on over 1,500 plant variables, alarms in case of dangerous trends, and prepares calculations which are used to economically balance operating conditions.

Another computer system application is control of the operation of analytical instruments in production control laboratories. In this type of system, a computer is connected directly to chromatographs and other laboratory instruments, and replaces tedious manual operations by preparing results of chemical analysis almost instantaneously. In one survey chemical plant, for

CHART 3. NUMBER OF DIGITAL PROCESS COMPUTER INSTALLATIONS REPORTED IN THE U.S. AND THE WORLD, SELECTED PERIODS, 1958-68



SOURCE: SEE TABLE 2.

1/ Includes computers installed and on order.

Table 2. Installations of digital process computers reported in the United States, by major categories of users, cumulative totals, 1958-68

Category	1958	1959	1960	Mar. 1961	Sept. 1963	Mar. 1965	Aug. 1965	Sept. 1966	Mar. 1967	July 1968[1]
United States, total	1	7	15	37	238	409	518	792	907	1,674
Process industries studied	1	7	15	37	175	293	340	445	496	738
Electric power	1	1	1	10	78	110	130	169	171	292
Industrial chemicals	0	0	5	8	31	60	72	90	120	156
Iron and steel	0	1	3	9	24	62	69	102	104	132
Petroleum refining	0	5	6	10	29	36	43	51	68	110
Pulp, paper, and board	0	0	0	0	10	17	17	19	19	28
Hydraulic cement	0	0	0	0	3	8	9	14	14	20
Other industry groups	0	0	0	0	63	116	178	347	411	936
Aerospace	0	0	0	0	13	15	23	101	125	252
Discrete manufacturing	0	0	0	0	8	24	34	56	60	178
Research, medicine, and education	0	0	0	0	19	26	45	69	72	166
Oil and natural gas production and pipelining	0	0	0	0	9	20	36	53	69	118
Miscellaneous	0	0	0	0	14	31	40	68	85	222

1 Total includes computers installed and on order.

SOURCE: Basic data used to compile the totals were obtained from *Control Engineering,* "Process Computer Scorecards," 1961-68. Dates used in the table, from March 1961 to July 1968, correspond to the dates of these "Scorecards." The *Control Engineering* data were supplemented and adjusted by using additional information from *Oil and Gas Journal,* "Computer Control in the Oil Industry," 1963-67; "Westinghouse, Installation List of Process Computers," 1966; *Iron and Steel Engineer,* "Process Computers—Their Place in the Steel Industry," 1965; "Manpower Implications of Process Control Computers in the Process Industries," a study prepared for the National Commission on Technology, Automation and Economic Progress, 1966; and information from survey field visits. (For more detail about most of these sources, see the selected annotated bibliography p. 63.)

example, such a system is leading to better control over operations in the total plant. Another survey plant is planning to install a similar system with the addition of remote stations connected to instruments in operating units in the plant so that results of analysis could be used immediately to adjust operating processes.

Control of ammonia production was another important computer task illustrated at a survey plant, where a computer provided closed-loop control over key portions of the process. The computer is used to control variables such as temperatures, pressures, flow rates, and gas and catalyst activity. The system also adjusts instruments to compensate for changes in weather and keeps the process operating economically.

Direct digital control (DDC) was in use at two chemical plants visited. In one facility, this advanced type of computer control was being used on an experimental basis for production of a detergent. The other facility, however, was using DDC for a larger operating unit. Both users reported significant improvement in control with DDC.

Iron and steel. Computers have been applied to many major operations in the cycle of making steel, from the initial steps of preparation of raw materials for the blast furnace to the final production of finished steel shapes. The use of process control computers in the basic oxygen steelmaking process, for example, is one of the most important applications. At a survey steel plant, the function of a computer system which is not connected directly to the process is to calculate and transmit to the furnace operator instructions about how much scrap, molten iron, flux, and oxygen to use for a specific heat.

Another important application, control of significant operations at a hot strip mill, was observed at a survey plant. Functions of the computer system included tracking the location of steel slabs being processed through the mill, controlling the rate of processing and the temperature and dimensions of the slabs, and collecting and recording production data. A different survey plant was using computers for control of electrolytic tinning lines. The system at this plant regulates the amount of tin deposited, based upon manually entered order data, and provides complete records for production, accounting, and quality control purposes.

Petroleum refining. Computer control of catalytic cracking, a refining operation that has numerous computer installations, was observed at one survey plant. The computer system is used to regulate temperature

Table 3. Computer applications in survey plants

Industry	Applications	Number of computer systems in survey
Electric power	Steam electric generating station	4
Industrial chemicals	Styrene process	1
	Ethanolamine process	1
	Ammonia process	1
	Multiplant production monitoring	1
	Control of all major processes in plant including manufacture of ethylene, benzene, other petrochemicals; steam generation; and plant utilities	[1]1
	Soft detergent process	[2]1
	Laboratory instruments (chromatographs) in production laboratory	1
	Laboratory instruments (chromatographs) in research laboratory	1
Iron and steel	Fuel and utilities utilization and power demand	1
	Basic oxygen furnace	1
	Hot strip mill	1
	Continuous annealing line	1
	Electrolytic tinning line	2
Petroleum refining	Crude distillation process	1
	Catalytic reforming process	1
	Polymerization process	1
	Catalytic cracking process	1
Pulp, paper, and board	Papermaking machine	1
Hydraulic cement rotary kiln	Rotary kiln	1

[1] 4 computers.
[2] 2 computers.

SOURCE: Plant visits.

and flow rates, thereby allowing the unit to operate closer to equipment limits. In addition, the system logs automatically 130 instrument readings per minute, a task that would be impossible to do manually.

Another primary application observed at a survey plant was control of a crude distillation unit. The computer, by means of an optimizing program, adjusts process instruments automatically to increase the proportion of high valued products in relation to low valued products, taking into account variables such as changes in raw materials, process balance, and external temperature. The system also logs data and alarms operators in case of malfunctions.

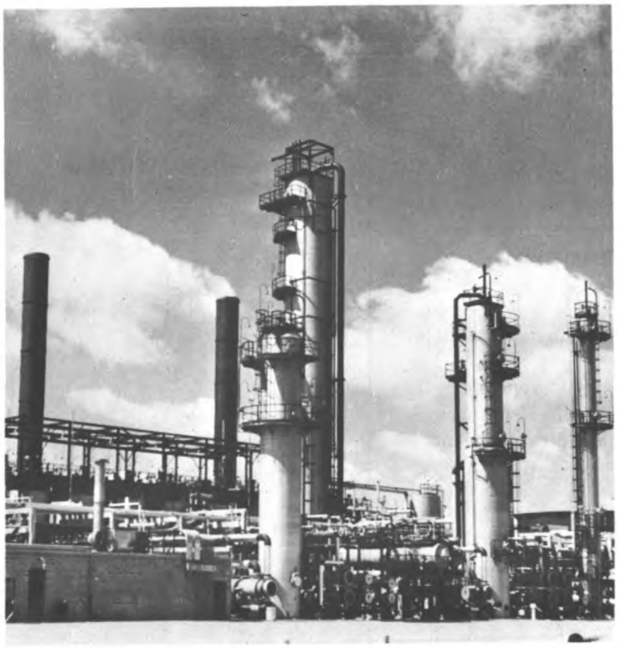
Pulp, paper and board. Control over a papermaking machine, the major computer application in the paper industry, was observed at a paper mill included in the study. The computer control system informs the crew when selected process variables are out of limits, and automatically adjusts the settings of instruments for changes in paper grade, weights, and moisture content. Both operator guide functions and automatic control functions are involved.

Hydraulic cement industry. Kiln control, which consists of the operation of a long rotating tube in which the blended raw materials for the manufacture of cement are heated, the most widely used computer application in the cement industry, was illustrated at a survey plant. The computer at this plant maintains automatic control over several key kiln variables, including kiln speed, and logs separate readings from 58 instruments in the kiln; over 500 readings are made every minute.

Application of Process Computers in Industries not Studied

Oil field control is a major computer application in the production of petroleum. A computer, linked to a large number of operating oil wells in a field, provides automatic pumping, sampling, and monitoring; prepares production reports; and indicates problem wells. Similar computer control systems are in use in natural gas fields.

Some Typical Control Rooms and Units Under Computer Control in Industries Studies



2

3

Catalytic Reformer in a Petroleum Refinery

4

5

Turbine – Generator in Electric Generating Station

Some Typical Control Rooms and Units Under Computer Control in Industries Studies

6

7

Basic Oxygen Furnace in Steel Plant

8

9

Kiln in Cement Plant

In the gas transmission industry, the key computer application is pipeline control.

The automobile industry is using an increasing number of process computers for applications such as quality control and parts matching on auto assembly lines, testing of subassemblies and completed autos, and control over drafting machines. Some computer applications in other durable goods industries are control over the manufacture of electronic components and the operation of banks of machine tools.

Process computers are used in the aerospace industry for applications such as missile launch and tracking, simulation studies of spacecraft and airplane operation, and static firing tests of jet and rocket engines.

Other computer applications include patient monitoring in hospitals; control of aluminum and copper refining operations and aluminum rolling mills; control over dyeing processes in the textile industry; traffic control; railroad car classification; and control of bakeries, warehouses, and mining operations.

CHAPTER 5. COSTS AND BENEFITS OF INSTALLING PROCESS CONTROL COMPUTERS

Management's decisions to adopt the new technology are affected greatly by the cost of installing process computer systems and the expected benefits to be gained. This chapter discusses the costs, benefits, and problems reported at survey plants.

Costs at Survey Plants

The computer and auxiliary equipment in survey plants were purchased, leased, or rented from system vendors. Costs of process computer systems at survey plants ranged from $200,000 to $1,500,000. (See tables 4 and 5 which provide information about the costs of purchasing, leasing, or renting selected process computers and other system costs.) One important factor determining the amount expended was the stage of development of the innovation. Early, pioneering installations had high costs due to the experimental nature of the technology. Time and technical effort involved tended to be greater than comparable, more recent installations. Numerous equipment and programing problems occurred with early installations. Some of the costs of the earlier projects, however, were underwritten by computer vendors in an effort to gain experience with process control computers and to gain a foothold in the industry.

A second factor affecting costs was the complexity of the installation. A system designed specifically for control over a small portion of a simple process, for example, especially one superimposed upon a preexisting, highly instrumented analog control system, cost much less than a highly complex, multicomputer system designed specifically for complete control over a newly-built major facility.

The degree of control of the system was a third determinant of its cost. Installations that were designed for fairly simple control functions, such as data logging, usually required less time, effort, and instrumentation than more highly sophisticated computer operations, such as automatic control, and therefore cost less to implement.

Replacement systems tended to be lower in cost than original installations largely because some of the programing and plant instrumentation could be carried over to the new system. Also, the cost of the replacement computer usually was appreciably less than the original unit, despite its increased speed, computing power, and reliability.

Objectives

The companies surveyed reported a number of major objectives for introducing computer process control. (See table 6.) Cost savings through lower raw material and fuel requirements was the most frequently cited objective, followed by the desire to optimize product mix and yield to produce a combination of products with the greatest market value. Other goals included increased production, expanded process knowledge, improved operating efficiency, and more experience in computer process control. Lowering manpower costs was an objective in only 4 of 12 survey plants, primarily because labor costs in units to be placed under computer control made up a relatively small proportion of total production costs at most survey plants. (However, in several instances, plants reported increased productivity, i.e., decreased unit labor requirements, as a result of increased output with the same size labor force.)

Benefits of Computer Control

Process control computers brought about significant operating improvements; the result was that the objectives cited in the preceding section generally were realized. The nature and extent of these improvements were influenced by factors such as market demand, degree of computer control, efficiency of preexisting conventional controls, and nature of the process controlled. Since these factors may vary over time and between and within plants, the case examples of achievements presented below should be considered as illustrative only. They could be significantly different in plants not surveyed or in survey plants at different times.

Examples of achievements at survey plants. Although computer installations at several survey plants were not fully operational, significant operating economies and

Table 4. Costs of selected process computer systems in survey plants with purchased computers

Type of application	Total cost	Computer and auxiliary equipment[1]		Programing and systems analysis[2]		Installation and additional instrumentation[3]		Training[4]	
		Amount	Percent of total system cost	Amount	Percent of total system cost	Amount	Percent of total system cost	Amount	Percent of total system cost
Multicomputer system controlling all major processes in large chemical plant	$1,500,000	$1,125,000	75.0	[5]$225,000	15.0	$150,000	10.0	-	-
Complex system for control of an electric generating station	850,000	400,000	47.1	190,000	22.4	250,000	29.4	10,000	1.2
Operator guide control over a major process in a steel plant	810,000	290,000	35.8	300,000	37.0	200,000	24.7	20,000	2.5
Operator guide control of electric generating station	720,000	300,000	41.7	140,000	19.4	275,000	38.2	5,000	.7
Direct digital control of a chemical process	500,000	275,000	55.0	75,000	15.0	150,000	30.0	-	-
Control over a key portion of a chemical process (early installation)	453,000	258,000	57.0	75,000	16.6	110,000	24.3	10,000	2.2
Control of analytical instruments in chemical plant laboratory	235,290	160,000	68.0	58,820	25.0	16,470	7.0	-	-
Experimental direct digital control system using 2 computers in a chemical plant	222,000	157,000	70.7	50,000	22.5	10,000	4.5	5,000	2.3

1 Central processor, auxiliary memory, analog/digital signal converters, and input/output equipment such as operator console, typewriters, and tape equipment.

2 Analysis of process, preparation of process model, programing for process control, and system operation.

3 New instrumentation needed for process control installation of computer equipment, and instrumentation including site preparation.

4 Instructing employees in programing, computer technology, maintenance, and system operation.

5 Includes training.

Table 5. Costs of selected process computer systems in survey plants with rented or leased computers

Type of application[1]	Rental or lease costs for computer and auxiliary equipment[2]	Programing and systems analysis[3]	Installation and additional instrumentation[4]	Training[5]
Control over key process in a paper plant	$14,000/mo.	$150,000	$200,000	$100,000
Control of a petroleum refining process (early installation)	7,500/mo.	250,000	100,000	2,000
Control over a complex petroleum refining process	7,500/mo.	250,000	200,000	5,000
Control over a key process in a paper plant (replacement computer)	7,000/mo.	80,000	30,000	30,000
Control over major portions of a cement manufacturing process	5,750/mo.	170,000	65,000	-

1 These applications involve varying levels of automatic control.
2 Rental or lease costs usually include costs of maintenance.
3 Analysis of process, preparation of process model, programing for process control, and system operation.
4 New instrumentation needed for process control, installation of computer equipment, and instrumentation including site preparation.
5 Instructing employees in programing, computer technology, maintenance, and system operation.

Table 6. Management's objectives in introducing computer process control

Objective	Number of times mentioned at survey plant[1]
Reduce raw material and fuel costs	9
Optimize production	6
Increase production	5
Increase process knowledge	4
Improve plant or unit operating efficiency	4
Improve product quality	4
Gain experience with computer process control	4
Reduce manpower requirements	4
Provide better or more rapid analysis	3
Increase equipment availability	2
Other[2]	5

1 Several objectives generally were given at each survey plant.
2 These objectives include the desire to improve data gathering procedures, reduce equipment damage, improve plant safety, achieve process stability, and increase information available to operators.

other benefits subject to measurement were reported at most plants.

Fuel and raw material savings were achieved at seven plants and anticipated at another; for example:

A chemical plant producing ammonia reduced raw material and fuel costs by 2 percent each.

A steel plant using process computers to optimize and predict fuel and power needs lowered fuel oil requirements by 4 percent and purchased power consumption by 6 percent.

At another steel plant, computer control of basic oxygen furnace operations for charge calculations, analysis, and data logging lowered oxygen costs by 5 percent, since fewer adjustments or corrections to the heats were needed.

Labor savings were achieved at three plants and expected at two others:

At a large petrochemical complex, a process control computer used for chemical anaylysis in an analytical laboratory brought about savings of $20,000 a year and displaced seven laboratory analysts due to more rapid and more accurate analysis of samples.

At a steel plant, savings from computer control of a hot strip mill resulted, in part, from lower unit labor requirements as throughput tonnage increased while the work staff increased proportionately much less. The higher throughput rate was brought about by faster slab processing and the ability to more quickly reset the mill for processing different steel products, enabling an extra 20 to 30 slabs to be produced per shift.

At the steel mill with the computer controlled basic oxygen furnace, labor requirements were lower by 5 percent because fewer manual operations were needed.

Production increased at 5 plants and was expected to increase at two others, for example:

At a paper plant, use of computer control and extensive new instrumentation on a paper machine reduced grade change time by 20 percent, increased speed by 15 percent, and improved machine efficiency 2 percent for a net increase in production of 19 percent.

A petroleum refinery achieved a 3 percent increase in the production of a polymerization unit with no increase in the amount of raw material used.

At a cement plant, computer control of a rotary kiln greatly reduced fluctuations from desired values and resulted in a more uniform product and 10 to 13 percent greater output.

Savings from computer control were quite substantial in some cases:

In a large new chemical plant, savings were estimated to be about $400,000 annually, based on comparison with an equivalent plant without computer control. Reduction in initial staffing saved $224,000, process improvements due to quicker access to data saved $120,000, and increased engineer and technician productivity saved $56,000.

At a petroleum refinery, the computer adjusts the control devices to compensate for sudden changes in the process more rapidly than was possible under manual control. Major sources of savings were higher yields of more valuable products and lower raw material and fuel costs. Another saving source was reduced maintenance costs, since the computer alerts personnel to conditions that could result in operating problems or malfunctions. In general, the process operated closer to theoretical optimum levels than under conventional control, and product specifications were met more consistently. Net annual savings were estimated at about $100,000 per computer.

In some cases achievements could not be measured precisely:

At a steel plant, the computer system used in a hot strip mill made possible more precise and more consistent control of mill operations, resulting in improved metallurgical and dimensional uniformity, fewer rejects, and higher quality end-products.

At an electric generating station, operating savings as a result of computer control were nebulous. Benefits such as improved engineering knowledge of the steam powerplant cycle, more accurate and up-to-date records, and better data to guide the operator in controlling the plant could not be measured in dollar terms.

At an electric generating station, temperatures and pressures were allowed to run slightly higher when using the computer system for monitoring the process. This permitted operating boilers and generators at the upper limit of capacity and, in effect, increased capacity.

In many of the installations, unanticipated benefits resulted from the introduction of a computer control system:

In a paper plant, the computer control system helped engineers to track down process and instrument problems by pinpointing the malfunction and defining it as one of production or instrument performance.

At a steel mill, use of computers on tinning lines improved quality of finished product by a greater degree than anticipated.

At a cement plant, improvement in the performance of the kiln operators was an unexpected benefit. During computer control, the kiln speed increased from the usual rate of 70 to 90 revolutions per hour. By working under these conditions, the kiln operators gained confidence in themselves and the equipment so that even when the computer was not controlling the process, they were able to operate the kiln at the higher speed.

In an electric generating station, engineers involved with applying computer control acquired additional knowledge about general plant engineering and operating conditions, control mathematics, computer maintenance, and trouble-shooting.

In another electric generating station, data quality and alarm system reliability were higher than anticipated, and the computer proved useful to laboratory technicians for precision testing and special analysis.

Problems at Survey Plants

Almost every installation reported some type of equipment malfunction, but usually these problems were relatively minor, such as an output typewriter not operating properly. The less frequent serious problems resulted from defective and unreliable instruments and computer components. A problem found in a number of early installations was the commercial unavailability of specialized instruments that were needed for computer control. Some of these devices, therefore, had to be designed individually and custom made. At a steel mill, for example, a special gage to measure continuously the hardness of steel strip had to be developed before the continuous annealing line operations could be controlled by computer.

The kinds of equipment problems experienced by survey plants are illustrated by the following examples.

At a pioneering installation in a petroleum refinery, a substantial amount of instrumentation was found to be unsuitable for computer control. All of this instrumentation had to be replaced. Morever, numerous failures of computer components caused complete, but temporary, shutdown of the computer control system. Satisfactory operation was attained only after much repair work by the computer manufacturer.

A chemical plant that had installed a multicomputer system also reported poor equipment reliability, especially during the first year of operation. Problems were reported with components such as computer air conditioners, magnetic tape circuitry, drum memory circuitry, input/output equipment, paper tape reader, and typewriters. Many of the problems with this installation were attributed to the early state of technology, since the system was designed around early model computers. Plans are to replace the present computers with more advanced and reliable equipment.

Programing difficulties were reported at a large number of survey projects. Many of these problems were due to insufficient technical knowledge of the process to be placed under computer control. Since many of the processes involved were very complex, programing effort was extensive. Moreover, even when the technical aspects of the process were understood, the problem of translating this knowledge into a working set of instructions for the computer had to be resolved. In some early installations, the vendor lacked sufficient technical knowledge of the process, and the user had to perform detailed investigations of the process to obtain suitable data for programing. At a steel mill, where a computer was installed to control a basic oxygen furnace, programing difficulties were reported and some aspects of the programing, which were the responsibility of the vendor, had to be assumed by user staff.

CHAPTER 6. MANPOWER FOR PLANNING AND IMPLEMENTING COMPUTER PROCESS CONTROL

Installation of computer process control required a large amount of technical, administrative, and manpower effort over a period generally exceeding 2 years and usually required considerable participation of vendor staff. This chapter discusses the characteristics of the project group, the manpower required by major phases of implementation, and the significance of prior EDP experience.

Characteristics and Function of the Project Group

Composition. Installation of computers at survey plants usually required considerable technical staff work. A project group consisting of managers, engineers, programers, and technicians was set up at each plant to plan and implement the installations. This group consisted of joint user and vendor staff for most installations. However, for a few projects, technical assistance was acquired from additional sources such as an outside consultant or contractor. The number of man-years of technical effort involved in implementing computer systems ranged from less than 2 for a relatively simple project involving replacement of an existing computer by a more powerful unit, to about 21 for a complicated electric generating application. (See table 7.)

User firms usually supplied the technical staff who knew the process, and the computer manufacturer usually supplied the personnel familiar with computer equipment operation, system capabilities, and programing. User technical staff assigned to the project group included managers, unit supervisors, process engineers, chemical engineers, electrical engineers, instrument engineers, and instrument technicians. These employees usually were drawn from process control and instrumentation departments at the plant level, and research and engineering departments at the corporate level. The computer vendor assigned systems engineers, statisticians, mathematicians, computer engineers, computer technicians, and programers to assist user staff in implementing the installations. As user technical personnel gained knowledge in computer operating technology, systems analysis, and programing, they assumed tasks that previously were performed by vendor personnel.

Number and type of employees involved. The size and composition of the project group at a survey plant depended upon the individual member's experience in process computer technology, the relative technical sophistication of the computer system to be installed, and the complexity of the computer application. At 23 installations surveyed, the project group varied in size from 3 to 23 members. Frequently, a member was involved in more than one stage of installation. Early installations at survey plants tended to have large project groups because vendor and user personnel lacked process computer experience. As technical staff gained experience with computer control, the size of the project group tended to reflect the complexity of the installation. Replacement systems at survey plants usually required a smaller project group than the original installation because some of the instrumentation and programs were carried over from the old system. Within individual projects, the size of the project group expanded or declined according to the phase of the work and the need for technical support. This point is illustrated in table 8, which provides information about the type and numbers of workers involved in planning and implementing computer applications at four survey plants.

Manpower Requirements by Major Installation Phases

The major phases in the installation of process control computer systems at survey plants and the manpower required for each phase were found to be difficult to enumerate and categorize, since project teams worked on different aspects of an installation during the same period and, therefore, steps overlapped. Despite this limitation, identification of the four major phases is possible at survey plants.

Feasibility study. The feasibility study, the first phase in most projects, usually was carried out by a relatively small group of employees, sometimes working with one of two computer vendor representatives. This step consisted of making a detailed study of the technical and

Table 7. Man-years required to implement computer process control at survey plants

Type of facility	Control application	Number of man-years required to reach operational phase	Months elapsed between installation and operational phase [1]
Papermill	Papermaking machine	-	21
	Papermaking machine [2]	-	[3] 6
Chemical plant	Styrene process	14.4	3
	Ethanolamine process	9.5	1
	Multiplant production monitoring	[3] 12.0-15.0	[3] 6
Chemical plant	Multicomputer operation of most of the processes in the plant	15.8	6
	Biodegradable linear alkylate	13.3	11
	Laboratory chromatograph analysis	6.1	5
Chemical plant	Ammonia process	7.5	-
	Ammonia process [2]	8.0	7
Petroleum refinery	Crude distillation process	20.0	6
	Catalytic reforming process	20.0	4
Petroleum refinery	Polymerization process	13.4	[4] 1-[5] 12
	Catalytic cracking	12.9	14
Cement plant	Rotary kiln	[3] 17.8-18.8	1
	Rotary kiln [2]	1.6	4
Steel mill	Fuel utilities utilization and power demand	-	6
	Basic oxygen furnace	5.1	7
Steel mill	Hot strip mill	-	-
Steel mill	Continuous annealing line	-	11
	Electrolytic tinning line	-	23
	Electrolytic tinning line	-	30
Electric powerplant	Coal-fired steam-driven electric generating station	20.8	24
	Coal-fired steam-driven electric generating station	15.4	9
Electric powerplant	Coal-fired steam-driven generating station	14.9	[3] 6
	Oil-fired steam-driven generating station	14.9	[3] 5

[1] The relatively long period between installation and operational phases reported at some survey plants generally resulted from unforeseen problems with computer components, programing, and instrumentation.
[2] Replacement computer for preceding application.
[3] Approximate.
[4] Partial control.
[5] Full control.

economic feasibility of applying computer control to a particular process, which involved (1) a detailed analysis of the process including material and energy flows, and (2) an estimate of potential benefits and costs. At a paper plant, for example, the feasibility study was accomplished over a period of 5 months by three relatively high-level employees—the managing director of research, the associate director of research, and the director of information services. In a chemical plant, the feasibility study for the first of four computer installations was conducted by the section head of the process laboratory and the section head of the computation lab. These employees worked for 2 months on this phase of the installation.

The time required to complete the feasibility study ranged from 2 months at one plant to 12 at another. However, a time span of 6 months or less was reported for about 3 out of every 4 computer installations studied.

Systems design, model building, and programing. The project group was expanded to accomplish system design, preinstallation planning, model building, and programing. At many installations, the group working on these steps consisted of 8 to 10 persons and reached a

Table 8. Personnel involved in planning and implementing process control computer systems at selected survey plants

Type of facility	Phase	Employees involved (user and vendor)		Implemented by	Duration of phase	Total number of man-months worked
		Type	Number			
Chemical plant	Feasibility study	Systems engineer	1	User and vendor	3 months	9 man-months
		Process engineer	1			
		Plant superintendent	1			
	Planning (including systems engineering and programing)	Systems engineer	2	User and vendor	12 months	96 man-months
		Process engineer	2			
		Instrument engineer	2			
		Plant programer	1			
		Plant superintendent	1			
	Installation	Systems engineer	2	User and vendor	1 month	5 man-months
		Process engineer	1			
		Programer	1			
		Plant superintendent	1			
	Operational	Systems engineer	1	User	Continuing	-
		Plant superintendent	1			
Petroleum refinery ...	Feasibility study	Process engineer (user)	2	User and vendor	6 months	24 man-months
		Engineers (vendor)	2			
	Systems engineering	Process engineer (user)	2½	User and vendor	6 months	33 man-months
		Instrument engineer (user)	1			
		Engineers (vendor)	2			
	Programing and program checkout	Process engineer (user)	2	User and vendor	12 months	36 man-months
		Engineer (vendor)	1			
	Installation and checkout of computer equipment	Process engineer (user)	2	User and vendor	4 months	20 man-months
		Instrument engineer (user)	2			
		Engineer (vendor)	1			
	Checkout of system instrumentation	Instrument technician (user)	2	User	24 months	48 man-months
Steel mill	Systems planning	Process engineer	1	User and vendor	6 months	9 man-months
		Systems engineer	2			
	Preparation of mathematical model	Process engineer	1	User	18 months	18 man-months
	Programing (including some training)	Systems engineer	2	User and vendor	11 months	22 man-months
	Installation	Electrical engineer	2	User and vendor	6 months	12 man-months
	System refinement and modification	Systems engineers	2	User	Continuing	-
Electric generating plant.	Planning and detailing specifications including feasibility study	Engineers (user)	8	User	4 months	9 man-months
	Basic programing	Programers	5	Vendor	6 months	30 man-months
	Application and support programing	Engineers	7	User	20 months	82 man-months
	Installation	Contractor personnel	10	Outside contractor	4 months	40 man-months
	Instrument calibration	Technicians	3	User	4 months	12 man-months
	Checkout of system	Engineer	1	User	3 months	6 man-months
		Engineering assistant	1			

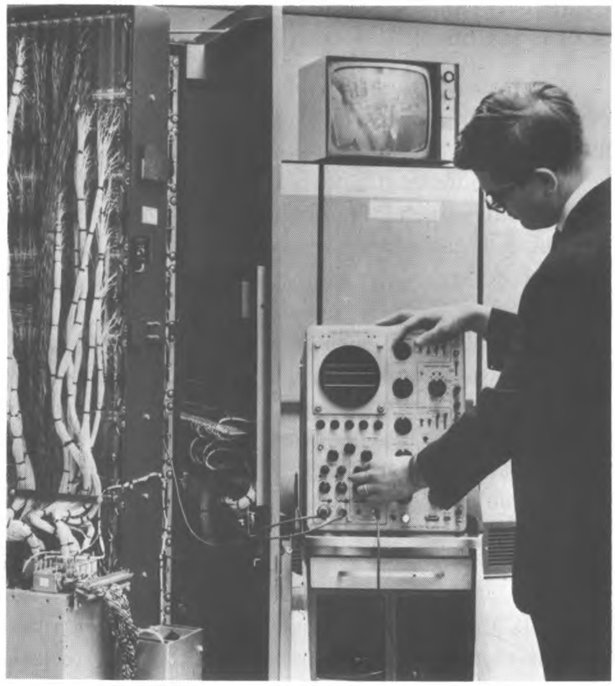
high of 23 people at one plant. Vendor participation was quite extensive, representing as much as half the project team in one case.

These steps consisted of developing computer equipment specifications, determining the type and degree of control desired, and planning the computer site and installation procedure. Specifications were determined for items such as the central processor, computer memory, and input/output equipment, and computer site. Existing instrumentation was surveyed to determine which instruments were suitable for computer control and what modifications to instrumentation were needed. Requirements for additional instrumentation were developed and orders placed with vendor firms. Plans for operating the computer, auxiliary equipment, and instrumentation as an integrated control unit were accomplished.

The necessary technical information about the process was gathered and consolidated to prepare a mathematical model of the process. Operating instructions for computer equipment and process control strategies were developed, and programs were written by translating the process model, control strategies, and computer operating instructions into a series of discrete arithmetic and logical statements. These programs were stored in the computer memory and carefully tested for malfunctions. The time required to complete this phase ranged from 12 to 43 months.

Installation. During the installation phase, the project group declined in size; most often it averaged from about 5 to 7 technicians and engineers. This phase consisted of installing the computer and auxiliary equipment at the process site. Existing instruments were modified, new instruments installed, and system components connected. The equipment, instrumentation, and wiring were checked carefully to prevent malfunctions. At a survey cement plant, for example, a process engineer, two systems engineers, and two electrician/instrument technicians accomplished the installation. In cases where problems arose, checkout of equipment after installation required considerable technical effort. At a petroleum refinery, for example, instrument checkout required more than twice the number of man-months than was needed to install the computer and related equipment. Vendor employees were involved in the installation of computer equipment in nearly all survey plant systems. Installation in survey plants was accomplished during a period of 1 to 6 months; equipment check-out usually took longer, up to 24 months in one case.

Operational and system refinement. The size and composition of the project group for the operational and system refinement phase depended mainly upon the



10. Engineer checks computer circuitry during installation at user plant.

degree of control desired. This phase consisted of the shift from manual to computer control of the process and lasted from 1 to 30 months after installation. (See table 7.) In most cases, the shift was accomplished gradually. Simple computer operations, such as data monitoring, were undertaken first, and more complex tasks, such as operator guide or closed-loop control, were accomplished later. In a cement plant, the shift from open-loop to closed-loop control involved eight people; an engineer, a process engineer, a program/systems engineer, and four electrician/instrument technicians who were assisted by a systems engineer from the vendor staff. Altogether, the project group spent 72 man-months in implementing a more advanced degree of computer control. System refinement, a continuing task at some survey plants, generally involved advancing the degree of control.

Once a computer system was operating satisfactorily and the desired degree of control was attained, one or two engineers who were plant employees and members of the project group usually remained with the system to assure that it continued to function smoothly. In a number of cases, however, the unit supervisor was the only member of the project team assigned to work permanently with the computer system. As a general rule, after the computer system became operational, vendor personnel were called upon only in emergency situations.

Status of the User Process Control Computer Group

A permanent group of employees worked on process computer applications in all but one survey plant. In most cases, this group was formed at the plant level, and its overall number fluctuated according to the complexity and scope of the project. Each group, however, contained a nucleus of technical employees who were involved continuously with some aspect of computer process control. In a plant with four systems, for example, a high level engineer was assigned permanently to the task of coordinating process control computers. This engineer augmented the size of the project team for each installation by borrowing personnel from relevant plant departments; after the installation was completed, these employees were reassigned.

A central process control computer group was formed at the corporate level in a number of the larger firms visited. In very large companies, as the number of installations in their plants increased, these companies often brought together key personnel at the corporate level who were experienced with computer control. These centralized groups consisted of employees with a knowledge of systems engineering, programing, computer technology, and process operation. The functions of these groups of employees were to develop new applications of process computers in corporate plants, to do research into advanced forms of computer process control, and to serve as a source of primary members for project teams in specific plant installations. At the two survey electric power companies, for example, a corporate computer group rather than a plant group was involved directly with programing and implementing process computers at company plants.

Staffing Problems

A lack of trained personnel experienced in applying control computers to industrial processes was cited as a serious problem by most survey plants. A number of specific problems were attributed to this scarcity of trained manpower. For example, at a cement plant, the lack of trained engineers with process computer knowledge was considered a handicap to its process control projects. A petroleum refinery had a large turnover in experienced technical personnel between the installation of its first and second process computer systems. This turnover necessitated using personnel inexperienced in computer technology for the second installation and required additional training sessions.

Significance of Prior EDP Experience

Extent of experience. Ten of the 12 plants visited either had been using business or scientific computers prior to the installation of process control computers, or had staff members with previous scientific or business computer experience. Applications of scientific computers at these plants included solving technical problems, performing simulation studies, and processing large volumes of operating data. Business computers were used for tasks such as accounting and payroll preparation. The two remaining plants had no computer experience prior to the installation of process control computers.

Transferability of skills. Six of the 10 plants that reported prior business or scientific computer experience indicated that personnel associated with these applications were of some help in the installation of process computers. At a chemical plant, for example, a knowledge of FORTRAN is considered useful in learning to program process computers. A steel plant found that prior experience with programing and systems design for business computers was useful but not of significant importance in its process computer projects. In a paper plant, some corporate level personnel with prior EDP experience were assigned to work on the process computer project. In general, however, these and other examples indicate that programing and computer skills are transferable only to a limited extent.

At a petroleum refinery, however, work with technical computers led directly to one of the earliest computer control installations in the industry. First, simulation studies of the process were performed on a technical computer, and then an offsite computer was connected to the process via data transmission lines. Finally, an onsite process computer was installed. The project team for the computer installation was expanded from a nucleus of employees who worked with the technical computers.

The remaining four plants with prior computer experience indicated that no transferability of skills was apparent between business or scientific computers and process computers. Those interviewed at these plants indicated that techniques needed for work with process control computers differed completely from those needed for work with business and scientific computers. Moreover, management at a power company preferred that project group engineers have no prior computer programing experience that could interfere with learning the company's special programing methods.

CHAPTER 7. IMPACT ON EMPLOYMENT AND JOBS

Although installation of process control computers resulted in practically no change in employment or displacement of individual workers, significant changes in job duties of operators, technicians, and other employees were reported at survey plants.

Changes in Employment

The installation of process computers had little immediate effect on employment in survey plants. Over the period that computers were installed, changes in general economic conditions, product demand, and the introduction of other forms of technology were the major factors that influenced the level of total plant employment. Except for one plant where all major processes are under computer control, workers in units using process computers made up a relatively small proportion of total plant employment, ranging from 0.1 percent in a steel mill to about 6 percent in a chemical plant. (See table 9.) The employment changes in survey plants varied greatly. At 6 of the 11 survey plants that provided data on employment, total plant employment increased over the period 1 year prior to the first computer installation to 1 year after the most recent installation; at the five other plants, employment declined.

Total employment in production units over the same period also was relatively unaffected by the introduction of process computers. Employment in 7 of the 12 computerized production units for which data were provided remained unchanged; employment increased at three other units, and declined at the remaining two units.

Table 9. Employment in computerized units as a percent of total employment in survey plants[1]

Plant	Total plant employment	Unit employment: Total	Unit employment: Percent of total plant employment
Papermill	740	35	4.7
Chemical facility	8,004	42	.5
		16	.2
Chemical facility	727	(2)	(2)
Chemical facility	470	[3] 26	5.5
Petroleum refinery	2,775	17	.6
		21	.8
Cement plant	359	17	4.7
Steel mill	18,945	386	2.0
Steel mill	12,375	214	1.7
Steel mill	13,973	19	.1
		23	.2
		27	.2

1 Most recent year available was used for those units for which employment data were provided. Comparable employment data not available at 3 survey plants.

2 Since all major production units at this plant are computer controlled workers in these units constitute a high but unspecified proportion of total employment.

3 Total for 2 units.

Displacement

According to management and union officials interviewed, no layoffs and little displacement took place in units with operations placed under computer control. Since labor costs made up a small proportion of total costs in most processes studied, the objectives for introducing computer control frequently were to increase or optimize production rather than to reduce manpower. Another reason for the relatively small displacement was that operating crews in the highly instrumented control rooms generally were at a minimum consistent with efficient operations prior to the introduction of the computer. Moreover, even though the computer eliminated some duties of these employees, the same size crew generally was retained to cope with any emergency arising from the malfunction of the computer or process equipment. In some cases, for example, operators were required to perform manual operations which duplicated automatic computer operations to retain skills needed for emergency manual control. In other instances, such as the computerized hot strip mill, operations normally shifted between manual and computer control, and, therefore, crews of the same size were needed and retained for both operations.

A few instances of displacement and reassignment to other plant units were reported. At a large chemical plant, for example, the jobs of 7 out of a total of 57 laboratory analysts were eliminated when a process computer system was introduced in a control laboratory to perform much of the computational, analytical, and data-logging operations formerly done manually by the analysts. The computer system automatically provides quick and accurate chemical analysis of a large volume of samples and produces finished laboratory reports. Of the seven laboratory analysts displaced, five were transferred and upgraded to higher-paying technician jobs elsewhere within the plant, one analyst died, and the other analyst went on military leave.

In another example of displacement, the jobs of three employees per shift at a petroleum refinery, a stillman and two stillman helpers, were eliminated as a result of the advanced forms of instrumentation installed as part of two computer control systems. A total of 13 employees in the two units were reassigned to jobs elsewhere in the plant.

One technique for measuring the displacement effect of computer process control is to compare manpower requirements of new plants designed for computer control with manpower requirements of plants of the same type and capacity using conventional control. Officials at a large survey chemical plant built with computer control estimated that about 20 employees more than the current complement of 300 production workers probably would be needed if the plant were not computer controlled. Fifteen of these employees would have been operators needed to log information and perform some control tasks; the other five would have been accounting clerks required to prepare summaries of operating data and other reports for management.

Changes in Job Duties and Skills

The single most important effect on employees in production units was the change in job duties. As indicated in table 10, process operator positions made up the majority of modified positions. The changes in their duties generally were caused by the shift from manual to automatic computer adjustment of instruments and related devices. The survey plants reported that the computer generates information not previously available on process conditions which the operator can use to "fine tune" the process and performs many calculations which were formerly done manually. Moreover, improved alarm systems incorporated in computer systems installed in survey plants in some instances greatly assisted the operator to perform monitoring duties. Some examples of changes in duties resulting from computer control are presented in table 11.

Table 10. Distribution of modified jobs at survey plants

Category	Modified jobs				
	Total number	Percent of total	In affected production units	In other units	Example of job titles used at survey plants
Total, all categories	352	100.0	249	103	
Managing or supervising	27	7.7	11	16	Production superintendent, general foreman, performance supervisor, shift foreman.
Systems engineering and related work	25	7.1	9	16	Plant test engineer, control engineer, results engineer, research engineer, instrument engineer.
Process operation	216	61.4	216	0	Machine tender, head operator, cracker operator, kiln burner, BOF operator, annealing line operator, boiler-turbine operator, clerk.
Laboratory analysis and related work	55	15.6	0	55	Laboratory technician, laboratory analyst.
Instrument maintenance and related work	29	8.2	13	16	Instrument technician, electronics repairman, electrician.

SOURCE: Data from 11 survey plants.

Table 11. Changes in major job duties of selected unit employees caused by computer process control

Job title	Unit	Description of major duties	
		Before computer control	After computer control
Machine tender	Paper machine in papermill.	Responsible for paper machine crew, and all paper made on machine. Checks papermaking equipment and customer order. Sets flows, temperatures, pressures and speeds at own discretion. Manually adjusts basis weight and moisture controls. Prints samples and checks paper for defects.	Computer sets flows, temperatures, pressures, and speeds and monitors these operations. Computer controls basis weight by changing stock flow, and controls moisture by changing steam flow. Machine tender performs some control and monitor duties as before and is available in case of emergency.
Clerk	Styrene unit in chemical plant.	Calculates operating ratios, manually logs gage readings, and prepares weekly plant reports.	Operates computer console and input/output equipment, translates information to and from machine language, feeds data into computer, operates off-line program to perform calculations, and interprets computer output. Compiles reports on a daily basis and calculates more operating ratios than before because computer makes more information available.
Head operator	Ethanolamine unit in chemical plant.	Controls unit by operating 40-foot control panel on plant floor with 40 to 60 different controls and gages. Manually adjusts analog controllers, reads and logs data, and performs simple chemical analysis.	Computer monitors, records, alarms, and manipulates process control mechanisms automatically. Operator sits in a minaturized control panel in air conditioned room and makes only a few manual adjustments to process variables, performs chemical analysis, and manually logs some data though the latter is not needed except to keep alert and abreast of process conditions.
Lab analyst	Control laboratory in chemical plant.	Performs numerous calculations for interpreting chromatograph charts to obtain chemical composition of process samples. Manually logs data and prepares reports.	Puts samples into chromatograph and adjusts setting on computer console while system automatically carries out analysis. Computer provides quick, accurate chemical analysis of sample data and finished reports for management use. The system eliminates human errors in calculation, and relieves lab analyst of monitoring functions. Lab analyst is free to perform nonroutine analysis.
Senior operator	Ammonia chemical plant.	Makes adjustments to process set points using manually-adjusted automatic controllers. Adjustments consist of minor changes in instrument settings to keep temperatures and gas composition within predetermined limits, and major changes to compensate for uncontrolled variables such as changes in weather.	Computer now makes most adjustments automatically; however, if major upset occurs, computer alarms operator and automatically shifts to manual control. Operator still performs many manual operations such as startup and shutdown of plant, and still writes out logging reports though computer automatically logs most important variables.
Operator	Polymerization unit in petroleum refinery.	Manually adjusts set points and controls unit using automatic controllers. Logs data manually, filling out data sheets by hand every 2 hours. Not able to log all data needed to run process at best levels.	Computer controls key temperatures, pressures, rates of flow, and catalytic process. However, it cannot cope with emergencies. Operator determines extent of problems, although computer assists by alarming and takes each loop or whole process off computer control if necessary. He performs numerous manual control operations.
Operator	Fluid catalytic cracking unit in petroleum refinery.	Manually adjusts automatic analog controllers at control console. Monitors automatic data logging equipment.	The computer controls a large part of process, although the operator still performs much manual control. The operator can take any part or the whole process off computer control in case of emergencies. The computer does most logging.

Table 11. Changes in major job duties of selected unit employees caused by computer process control—Continued

Job title	Unit	Description of major duties	
		Before computer control	After computer control
Kiln burner	Kiln department in cement plant.	Monitors and adjusts instruments manually or by adjusting set points on automatic analog controller to control variables such as kiln temperature, speed, raw material feed rate, etc., relying mainly upon experience as guide. Maintains records manually.	Computer scans process and automatically makes adjustments of key variables, including kiln speed. Computer monitors numerous other variables, reads instruments, compares and analyzes data, and prints out reports. Kiln burner uses these reports to make changes manually or to adjust set points on controllers.
BOF operator	Basic oxygen furnace in steel mill.	When computer not operating:[1] Operates and monitors numerous levers, dials, and other devices in controlling the furnace. Refers to set of charts to derive proper quantities of scrap, hot metal, lime, and oxygen to use for specific heat.	When computer operating:[1] Operates computer which calculates and transmits instructions on amount of scrap, molten iron, lime, and oxygen to use in preparing specific heat. Adjusts control devices so that predetermined additives will be fed into furnace. Prepares production reports using computer-supplied data. Has option of making adjustments to the computer-generated instructions and occasionally verifies computer instructions by manually making computations based on data in sets of charts.
Plater operator	Tinning line in steel mill.	Checks and makes corrections in process to maintain strip quality. Selects group of plating cells to be used for specific order, uses efficiency formula to determine amount of current to be sent through plating cells for specific line speed and coating weight, and manually adjusts plating current accordingly. Responsible for production equipment; establishes plating, current, and line speed practices; and all required records.	Selects plating cells to be used in the same manner as before, but computer automatically adjusts current for specific line speed and coating weight based on incoming order data and an efficiency formula which are manually dialed into the computer memory. Still monitors instruments and, if necessary, overrides system and adjusts current flow manually. Relieved of some monitoring duties because computer monitors and alarms in case of trouble.
Annealing line operator	Continuous annealing line in steel mill.	When computer not operating:[1] Manually set dial to desired temperature for each of eight furnace zones based on formula which considers strip thickness, line speed, and temperature. Sets production schedules, maintains line speed, furnace temperature, and related variables, and monitors control panels.	When computer operating:[1] Computer monitors and operates some controls. Operator oversees computer output equipment and modifies computer program to improve control of annealing line. Other duties same as before.
Boiler-turbine control operator	Electric generating station.	When computer not operating:[1] Operates boiler and turbine control panels to maintain proper steam temperature and pressure, fuel supply, and efficient combustion conditions. Starts up and shuts down turbine-generator unit, synchronizes generators, and regulates load voltage and frequency. Performs switching operations by remote control to maintain continuity of service and keeps extensive manual data logs.	When computer operating:[1] Operator performs many of the same duties as before, since computer operates primarily as a data logger. With the aid of the computer, operator controls boiler and turbine operations through dials and gages located on central control console and decides what pressures, temperatures, speeds, etc., should be changed and to what degree. Keeps only small log sheet since computer does most logging. Previously teletyped information to load dispatching, but now computer sends data automatically.
Results engineer	Electric generating station	When computer not operating:[1] Responsible for overall operation and performance of controls and instruments. Makes performance calculations, insures water purity, checks coal quality, etc. Studies long-term trend data and uses it to reduce losses and improve equipment, raw material and fuel use, and other operating efficiencies.	When computer operating:[1] Uses computer to aid in making performance calculations more frequently and more accurately. Computer, though not fully operational, reduces time spent on calculations and allows more time for analyzing data and making recommendations for better plant performance.

[1] Unit built with computer control.

11. Operator checks computer analysis of crude oil distillation unit in a petroleum refinery.

The installation of process computers, in addition to resulting in a modification of existing jobs, required a number of new positions as discussed in chapter 8.

How jobs are modified in a unit where computer control is installed is illustrated by the experiences at an 80-inch hot strip mill in a steel plant. This mill was operating approximately 75 percent of scheduled production runs under computer control when visited by BLS staff, and conventional control the remaining 25 percent of the time. Computer control will be extended, however, when programs are written to handle certain types of steel which presently are processed under conventional control.

The most distinguishing advantage of the computer-run 80-inch mill is its greater speed in producing uniform products within specifications. Under conventional control, operators make settings from reference tables based on standard width and rolling resistance specifications of various steel grades. Operators need about 2 minutes under normal conditions to reset a mill for processing a slab order that varies from the preceding slab rolled; the computer resetting time is only 6-8 seconds for the entire mill. During rolling operations under manual control, operators make adjustments to the standard settings, but the speed of the mill is limited by the ability of the operators to react to changing mill conditions. In comparison, the computer reacts almost instantaneously.

Of 33 existing occupations in the hot strip mill, duties of only 9 were modified by computer control while the remaining 24 were unaffected. Forty employees, or 19 percent of the total mill work force, were employed in these nine occupations at the time of visit. The extent to which the computer modifies each of the nine preexisting positions is shown in table 12.

Table 12. Extent of job modifications in hot strip mill

Occupation title	Total number of major duties	Major duties automated by computer [1]	
		Number	Percent
Total	84	26	31.0
Recorder	10	5	50.0
Assistant roller	12	5	41.7
Coiler operator	8	3	37.5
No. 1 rougher operator	13	4	30.8
No. 2 rougher operator	12	3	25.0
Speed operator	8	2	25.0
Crop shearman	9	2	22.2
Roll hand	6	1	16.7
Assistant speed operator	6	1	16.7

1 Performed automatically when mill is under computer control.

SOURCE: Company records.

Job duties of the three positions affected most by computer control——recorder, assistant roller, and coiler operator——are shown in appendix B-3. This information, taken from company job descriptions, shows that the duties performed automatically by the computer are crucial to the operation of the mill. Consequently, in many computer installations, operators continue to log data and adjust variables even after the computer assumes these functions. If the computer should fail or prove inadequate to cope with certain situations, the operator is called on to perform these duties. Therefore, he must retain his proficiency at controlling the process.

A list of the 26 major job duties performed automatically under computer control, by functions, is provided in table 13.

A number of employees outside of units using process computers also experienced changes in job duties and skills in survey plants, as indicated in table 11.

At a petroleum refinery, for example, nine instrument men were given training in computer and instrument maintenance and were assigned to perform normal maintenance and repairs on the computers and related instrumentation installed in two units. These workers

Computer Process Control System in a Hot Strip Mill in a Steel Plant

12. Computer Center

14. Hot Strip Mill
Finishing Stands

13. Control Pulpit

Table 13. Type of job duties performed by computer in hot strip mill

Function	Number of major job duties involving this function performed automatically under computer control	
	Number	Percent of total[1]
Total	26	100.0
Operate or set controls	14	53.8
Record data	5	19.2
Receive and/or communicate information	5	19.2
Operate equipment	2	7.7

1 Because of rounding, the sums of individual items may not equal 100.

required greater skill and ability than instrument men working on conventional equipment. These men were selected from employees who had received additonal electronics training previously; however, their job classifications and wages were not changed.

Changes in Grade Status

Most of the production workers in the affected units did not experience a change in grade status due to computer process control. Although some jobs were modified, these changes, for the most part, encompassed only a portion of the total duties of these positions and were not sufficient to result in a higher wage classification. In at least one instance, changes in job duties which may have resulted in upgrading were offset by substantially improved working conditions, a factor also considered in wage determination. Moreover, job descriptions were general in content, allowing considerable changes in jobs without reclassification.

In a few instances, however, employees were upgraded because of the change. The installation of a process computer at a large chemical plant, for example, resulted in the upgrading of four operators by one rate step. A formal job evaluation study indicated that these operators had assumed additional responsibilities. In the new system, operators had to interpret a significant amount of data provided by the computer and, as a result, were expected to run the plant closer to operating limits. However, physical working conditions, a factor in the job evaluation system, remained essentially the same.

CHAPTER 8. NEW JOBS REQUIRED FOR COMPUTER PROCESS CONTROL

New occupations are required as a result of the introduction of computers. In the survey plants, most of these occupations were professional and technical positions requiring persons with a college degree in engineering and related fields and a knowledge of the process to be controlled.

15. Systems engineer programing a process control computer system.

Type and Description of New Jobs

Substantial technical manpower is required to accomplish the various tasks involved in introducing computer process control. A total of 68 new jobs were needed in survey plants to plan, program, operate, and maintain the new computer control systems.

The new computer jobs can be classified into five major occupational categories. As shown in table 14, programing and systems analysis, design, or related work constituted about two-thirds of all new jobs; each of these two occupational groups included about the same number of jobs. The operation and maintenance of the computer equipment provided relatively small proportions of the new jobs, since these were among the functions that were included in existing jobs without changes in job title.

Table 14. New computer jobs at survey plants

Category	New jobs		Example of job titles used in survey plant
	Number	Percent of total	
Total, all categories	68	100.0	
Managing or supervising	12	17.6	Coordinator of refinery computer system, technical superintendent, chief systems analyst, senior process engineer.
Systems analysis, design, or related work	24	35.3	Senior design engineer, project scientist, systems analyst, process control engineer, senior research engineer.
Programing	22	32.4	Programer, programing technician, technical analyst, procedures analyst.
Operating computer consoles and related equipment	5	7.4	Computer console operator.
Instrument development, installation, maintenance, or related work	5	7.4	Instrument technician, electronic specialist, assistant test engineer.

Because computer control is a relatively new and emerging technology, the title and content of new jobs within the major functional job categories vary significantly between survey plants. An employee whose major job duty is programing is classified as a technical analyst at a petroleum refinery, a procedures analyst at a steel mill, and an engineering assistant at an electric power plant. Job titles used to designate the programing function at other plants are: Programer analyst at a petroleum refinery, programer at a cement plant, and programing technician at a chemical plant.

The degree of specialization in the various jobs also differs significantly in survey plants. In some plants, one or more major functions are merged into one job classification. At a paper mill, for example, the same job classification for systems analyst-programer and programer-computer operator is used. Even where job titles in one survey plant are approximately the same as in another, substantial variation in job content is sometimes found. Moreover, in a few plants, employees involved with computer process control also work on scientific and related computer applications.[3]

Some insight into the job duties of employees in new computer occupations can be obtained by examining the content of seven new positions at a paper mill. (See table 15.) Examples from each of the five broad functional occupational groups contained in table 14 are presented.

Selecting Employees for New Jobs

The duties of a significant number of new computer jobs required that the incumbent have a highly specialized technical knowledge of the process to be controlled, particularly the engineers and technicians who were engaged in system analysis, design, and related work and the programers. Consequently, most employees selected for new computer jobs were recruited from among the existing work force in survey plants. Of the 60 employees in new computer occupations for whom data on prior work experience were available, about 88 percent were working in the survey plants prior to installation of the computer systems, about 8 percent were formerly with another plant of the same company, and only slightly over 3 percent were hired from the outside.

The procedure in most survey plants was to train engineers and other technical staff in systems analysis and programing rather than to use systems analysts and programers with business data processing experience and expect them to acquire a knowledge of a complex industrial process. Although the techniques required to perform systems analysis and programing functions for a process control computer system were in many respects similar to those used in a business data processing computer system, the systems analyst and programer involved with process control usually must have a high degree of specialized technical knowledge (engineering, chemistry, and physics, for example) which is significantly different than the skill and knowledge needed to implement business data processing systems.

The criteria most frequently considered in selecting employees for new computer jobs were prior work experience, education, and interest. (Most of the new computer jobs were not under union jurisdiction and therefore the selection methods were not governed by formal procedures spelled out in collective bargaining agreements.) Formal aptitude tests as a means of selecting employees for new jobs were used in only a few instances. However, they sometimes carried considerable weight in the selection process. The four new computer console operator positions associated with a computerized hot strip mill, mentioned earlier, were staffed from among a group of about 66 clerks who applied for and completed a series of tests.[4]

The four applicants with the highest test scores were chosen for the new computer console operator positions. However, at other survey plants, aptitude tests only supplemented other techniques of selection. Employees being considered for programer positions at a chemical plant and paper mill took a programer aptitude test which was considered along with work experience and education in determining who would staff these new programer jobs.

Extent of Upgrading

Employees assigned to new computer jobs generally were upgraded. Table 16 indicates that two-thirds of 27 employees selected to staff new jobs received a wage increase of 20 percent or more. These increases frequently resulted because professional and technical employees acquired new skills through training and thus were able to perform the duties of the more responsible and higher-paying computer positions. A technical assistant at a survey petroleum refinery, for example, whose major duties involved general clerical tasks,

[3] This lack of standardization of job content and title also existed for occupations associated with the early stages of use of electronic computers for business data processing. See *Adjustments to the Introduction of Office Automation* (BLS Bulletin 1276) May 1960.

[4] These tests included the Watson–Glaser test of syllogistic problems which is designed to appraise ability to reason analytically and logically; and the Wonderlic personnel test of problem solving ability consisting of verbal, arithmetic, geometric, and vocabulary problems.

Table 15. Description of duties of new computer process control occupations at a papermill

Job title	Description of major duties
Manager, computer systems and programing	Supervises the development and implementation of digital computer programs and procedures designed to control papermaking process. Acts as consultant to corporate research staff in the development and implementation of computer programs and systems. Some major duties include defining programs into specific computer requirements, recommending computer equipment to be purchased or leased, developing or supervising the development of computer programs and procedural systems, and overseeing testing, debugging, and implementation of the approved program. The manager of computer systems and programing also has responsibility for training personnel in the use of process control computers and programing techniques, and for providing technical assistance on matters pertaining to process control computers. He works under the direction of the associate director, process control.
Systems analyst-programer	Investigates and analyzes operational problems and prepares and carries out proposals for new systems, procedures, or computer programs. He prepares operating procedures; draws flow charts and diagrams to define programing problems and procedures to be followed; checks programs for completeness and accuracy; evaluates and modifies existing programs; translates flow chart information into coded machine instructions and prepares other guides for use by the machine operator; and performs related duties. He also does a limited amount of programing work. The systems-analyst programer is under the supervision of the manager, computer systems and programing.
Senior process control engineer	Supervises process control of papermaking operations. This function encompasses problem analysis, data collection, standards development, programing, and computer operation. He has complete responsibility for the effective use of an electronic computer and related equipment to control selected papermaking operations. Some specific duties include applying guidance to the process engineer and the computer programer; planning and implementing process control activities to assure optimum utilization of equipment; acting as liaison between the mill (where the computer is used) and corporate research (where research on process control in undertaken) to assure coordination of computer process control activities; providing technical assistance to other company staff engaged in computer process control activities; and performing related duties pertaining to the implementation and maintenance of computer process control. The senior process control engineer works under the direction of the assistant division manager.
Computer programer	Develops, prepares, and tests programs which will solve scientific, mathematical, and technical problems associated with computer process control of selected papermaking processes. He develops and designs formulas, flow charts, and other descriptive material; designs programs which directs the computer to produce the desired production results; checks computer equipment to verify proper operating condition and notifies computer manufacturer technical staff when maintenance or repair work in needed; provides programing assistance in collection of data for research projects and performs related duties. The computer programer works under the direction of the senior process engineer.
Programer-computer operator	Assists in the development and preparation of new programs and the modification of those already prepared. He is responsible for the less complex programs or segments of larger programs. Specific duties include programing in a computer language, converting the computer language to machine language through a processor program, and testing and debugging the program. He also may operate computer equipment to run programs when requested. He receives technical advice from other staff members on aspects of programing which involve instrumentation, engineering, etc. The programer-computer operator is supervised by the manager, computer systems and programing.

Table 15. Description of duties of new computer process control occupations at a papermill—Continued

Job title	Description of major duties
Junior programer	Prepares digital computer programs necessary to solve scientific, mathematical and technical problems related to the control of papermaking processes. He prepares flow charts for less complex programs; codes flow chart information into FORTRAN, symbolic language, or machine instructions; checks programs for completeness and accuracy during test runs; makes a diagnosis of problems and corrects them as they occur; and performs related duties. The junior programer works under the direction of a systems analyst or senior programer.
Electronic specialist	Develops and refines laboratory and process instruments and control systems; operates, calibrates, adjusts, and checks instrument and control systems; conducts instrument and control evaluations and reports the results; and performs related duties. Work assignments sometimes involve mill trials and startups, pilot plant trials, and laboratory experimentation. Requires a background in advanced mathematics, physics, and electron theory; a high school diploma; and a passing grade on a special qualifying examination.

completed programing training and was upgraded to a technical analyst position involving computer programing. His new job pays nearly one-third more than his former position. At a paper mill, a powerhouse fireman with some college education passed a programer aptitude test and did well in a series of interviews, completed programer training, and is now a computer programer making 50 percent more than before. Moreover, some maintenance workers and computer console operators receive more money in their new jobs because responsibility for equipment and product is greater than before.

Because of the expected continued shortage of technical employees with computer process control experience, the wage level for these new occupations probably will continue to be relatively high, and there will be promotional opportunities for qualified employees.

Characteristics of Employees in New Jobs

Some insight into the manpower implications of computer process control can be assessed by examining the age, sex, education, and seniority of employees selected for new computer jobs. Comparison of these characteristics with those of employees working in the production units where computers were installed is of interest. The data for both of these groups are presented in tables 17 and 18.

Table 16. Extent of upgrading of employees selected to staff new computer jobs[1]

Category	Total number of employees for whom data were available	Number of employees whose wage increase was—				
		Less than 10 percent	10 to 19 percent	20 to 29 percent	30 to 39 percent	40 percent or over
Total	27	2	7	4	5	9
Managing or supervising	2	1			1	
Systems analysis, design, and related work	8		2		1	5
Programing	11		2	2	3	4
Operating computer consoles and related equipment	4	1	1	2		
Instrument development, installation, maintenance, or related work	2		2			

[1] Data were available for 27 of the 68 employees in new positions. The amount of wage increase is based on a comparison between the rate applicable to an employee's former position, just prior to installation of the process control system, and the rate assigned the new computer job. Several officials interviewed stressed that factors other than the new computer control systems, such as normal professional advancement, account for a portion of the increases. No employee moving into a new computer job for whom information on job status was available received a wage lower than his prior position.

Table 17. Age, education, and seniority: Employees in new computer process control positions and those in affected production units

Characteristic	Employees in new process control computer jobs		Employees in affected production units where process control computers were installed[1]	
	Number	Percent of total[2]	Number	Percent of total[2]
Age				
Total, all ages	68	100.0	223	100.0
Under age 25	6	8.8	6	2.7
Age 25-44	50	73.5	142	63.7
Age 45 and over	10	14.7	74	33.2
Unknown	2	2.9	1	.4
Education				
Total, all groups	68	100.0	223	100.0
Less than high school graduate	1	1.5	72	32.3
High school graduate	9	13.2	132	59.2
Some college	16	23.5	6	2.7
College graduate	42	61.8	5	2.2
Unknown	0	-	8	3.6
Seniority				
Total, all groups	68	100.0	223	100.0
With company:				
Less than 10 years	38	55.9	35	15.7
10-19 years	18	26.5	101	45.3
20 years or more	4	5.9	87	39.0
Unknown	8	11.8	-	-
Total, all groups	68	100.0	223	100.0
Present jobs:				
Less than 5 years	55	80.9	75	33.6
5-9 years	5	7.4	87	39.0
10 years or more	0	-	61	27.4
Unknown	8	11.8	-	-

1 Data were available for only 223 out of the more than 1,600 employees working in affected production units. Of these 223 employees, about 78 percent were operators and assistants, 11 percent were supervisors, 9 percent were technicians and technicians assistants, and 2 percent were clerks, materials handlers, and related employees.

2 Because of rounding, sum of individual percentages may not equal 100.0.

Sex and age. All employees in new computer jobs were men, and about 82 percent were under 45 years old at the time of the plant surveys.[5] Managers and supervisors and those performing systems analysis, design, and related work were somewhat older than those in the other categories of new computer occupations shown in table 18.

Employees in production units where computers are being used were also men. However, in contrast to employees in new computer jobs, about two-thirds of this group were under age 45.

Education. Although several important jobs were filled by training employees with a high school education, most of the new computer jobs were filled by college graduates, many with degrees in engineering, mathematics, and related fields. (See table 18.) Jobs involving supervision, systems analysis, process control engineering, and high-level programing required college training.

A high school diploma, or at least some high school education, was sufficient for some jobs. At a paper mill, a lab technician who was a high school graduate received training and was upgraded to a junior programer position. At a steel mill, four clerks, including two with only 3 years of high school, achieved the highest scores in a series of aptitude tests and were selected and trained as computer console operators. Moreover, most of the instrument installation and maintenance jobs in survey plants, such as electronic specialist positions in a paper mill, were staffed by high school graduates.

Employees in production units using process computers had significantly less formal education than those in new computer jobs. About 59 percent of this group were high school graduates, and about 32 percent had less than a high school education.

The significantly higher educational attainment of many of the employees in computer and related jobs is not surprising. The skill, knowledge, and experience required to plan and implement a process control computer installation is far different from that required to perform the duties of a production job in the affected units. Engineers, mathematicians, and other professional employees with college training are essential, and, as shown above, frequently make up a large segment of the

5 These finding differ significantly from an earlier BLS study which presented age and sex data for employees in offices using electronic computers for business data processing. In offices surveyed for this study, women staffed 11 percent of the new computer occupations and 53 percent of all jobs in affected office units. The variation in composition of the work force, by sex, reflects primarily the difference between an industrial environment, predominated by men, and a business office where women make up a significant segment of the staff. Employees in the new business data processing computer occupations were also somewhat younger than those in the new process control computer occupations. See *Adjustments to the Introduction of Office Automation,* (BLS Bulletin 1276) May 1960, 86 pp.

Table 18. Education of employees in new computer jobs, by category of job

Occupational group	Total in new jobs		Education			
			Percent of employees			
	Number	Percent	Less than high school graduate	High school graduate	Some college	College graduate
Total, all groups	68	100.0	1.5	13.2	23.5	61.8
Employees whose major duties involve:						
Managing or supervising	12	100.0	0	0	0	100.0
System analysis, design, or related work	24	100.0	0	0	4.2	95.8
Programing	22	100.0	0	13.6	59.1	27.3
Operating computer consoles and related equipment	5	100.0	20.0	40.0	40.0	0
Instrument development, installation, maintenance, or related work	5	100.0	0	80.0	0	20.0

project staff. Although production workers in the highly instrumented environment of a modern process plant also need skills and knowledge of a high degree, this skill and knowledge generally is acquired through job oriented classroom and on-the-job training rather than in a college or university.

Seniority. Employees in new computer jobs had significantly less company seniority than those working in affected production units. About 56 percent of those employed in computer occupations at the time of the plant survey had less than 10 years of company service; 27 percent had 10 to 19 years, and only 6 percent had been employed 20 years or more. For employees in production units, the proportion in these categories were 16, 45, and 39 percent, respectively.

Employees in the two groups differed even more sharply in terms of length of service in their present jobs. Because the computer units were relatively new, most of the employees had less than 5 years of continuous service in their present positions. On the other hand, most of the employees in production units had more than 5 years of service in their present positions. About one-fourth of the production unit employees had 10 or more years of service in their current jobs.

CHAPTER 9. TRAINING FOR COMPUTER PROCESS CONTROL

Training to provide employees with programing, maintenance, and operating skills is a key requirement to the successful introduction and use of computer process control. This training usually consists of intensive on-the-job and classroom programs conducted by vendors and users of process computers.

Training Provided by Vendors

Computer manufacturers provided a variety of training services to survey plants which purchased their computers. (See table 19.) Training involved classroom and on-the-job instruction at the site of the computer installation, and classroom and workshop or laboratory sessions at training facilities maintained by the computer vendor. Employees received full wages and salaries and, where applicable, travel allowances while undergoing training. A total of 154 employees at 11 survey plants received some form of vendor training. Provisions for this training were included in several of the lease or purchase agreements with vendors.

Onsite vendor training. This form of training, often in the nature of computer orientation, was relatively brief and tailored to meet the needs of workers in different occupational groups. Specialized training of longer duration also was provided when necessary.

Vendor staff sometimes joined with personnel of user companies and with representatives of other equipment suppliers in furnishing instruction. At an electric power plant, for example, representatives of the computer vendor, suppliers of related plant equipment, and instrument manufacturers participated with plant engineers in orientation lectures for operators and technicians.

Offsite vendor training. Facilities for customer training were maintained by four suppliers of computers; a fifth vendor provided brief equipment familiarization at one of its offices to a plant supervisor. Offsite vendor training facilities generally are maintained at a single location, although one vendor offered its courses at centers in several locations.

These schools or training centers provided instruction in computer concepts and fundamentals, programing, and maintenance. They were attended primarily by control group managers, systems engineers, programers, instrument engineers, and maintenance foremen. Several electronics technicians and a program maintenance technician also received training at vendor schools.

Courses of instruction offered at vendor schools are designed primarily for training managerial and technical personnel. Although the curricula vary at vendor schools, all of them provide courses which fall into the broad categories of maintenance and programing. In addition, some vendor schools offer specialized computer concepts courses for managerial personnel. A description of selected courses offered by one vendor is shown in table 20. Programing courses usually are from 2 to 4 weeks in length, while general maintenance courses may last from 8 to 12 weeks. Concepts courses, intended primarily for supervisors, are comparatively brief.

One vendor offers audio-taped programing courses that may be completed at the training center or at a location convenient to the student. This procedure lowers the cost of instruction and permits the student to progress at his own pace. Another vendor has developed a programing course in FORTRAN to be completed by the trainee before his enrollment in programing courses at the vendor's school.

16. Instructor explains maintenance procedures for computer equipment at computer training school.

Table 19. Training provided by computer manufacturers[1]

Recipient(s) of training	Number trained	Type of training	Description of training	Length of training
Papermill				
Instrument engineers	2	Classroom	Onsite instruction in computer concepts and FORTRAN provided jointly with user company staff. Process systems engineers and programers received additional training in concepts, hardware, machine, and symbolic language, FORTRAN programing, and executive systems at vendor facility.	2 weeks
Project leader	1	Classroom		2 weeks
Manager, computer systems and programing	1	Classroom		2 weeks
Keypunch operator	1	Classroom		2 weeks
Process systems engineers	6	Classroom		6 weeks
Programers	4	Classroom		6 weeks
Programer-operator	1	Classroom		6 weeks
Chemical plant				
Instrument engineer	1	Classroom	Computer technology, maintenance, and programing.	3 months
Programer	1	Classroom	Programing.	1 month
Process engineers	2	Classroom	Computer concepts and programing.	1 month
Chemical plant				
Engineer	1	Classroom	Computer maintenance.	4 months
Program maintenance technician	1	Classroom and on-the-job	Programing and computer techniques jointly with user staff onsite and at vendor facility.	12 months
Chemical plant				
Project team	12	Classroom	General details of computer system onsite.	Not provided
Project engineer	1	Classroom	Programing and theory of computer operation.	4-6 weeks
Process engineer	1	Classroom	Programing and theory of computer operation.	4-6 weeks
Construction engineer	1	Classroom	Programing and theory of computer operation.	4-6 weeks
Maintenance foreman	2	Classroom	Computer technology and maintenance.	9 weeks
Electronic and instrument mechanics	2	Classroom	Computer technology and maintenance.	9 weeks
Electrical engineer	1	Classroom	Computer technology and maintenance.	9 weeks
Engineers	4	Classroom	Programing techniques.	4-6 weeks
Petroleum refinery				
Technical employees	7	Classroom	Programing techniques and computer operation.	1-4 weeks
Petroleum refinery				
Programers	2	Classroom	Programing techniques.	3 weeks
Instrument engineers	1	Classroom	Computer maintenance and theory.	8 weeks
Instrument supervisors	1	Classroom	Computer maintenance and theory.	4 weeks
Instrument men	1	Classroom	Computer maintenance and theory.	12 weeks

See footnote at end of table.

Table 19. Training provided by computer manufacturers[1]—Continued

Recipient(s) of training	Number trained	Type of training	Description of training	Length of training
Petroleum refinery—Continued			3 instrument engineers, 6 instrument supervisors, and 6 instrument men (including above 3 employees) received 30 hours classroom instruction in computer theory onsite.	
Programers	7	Classroom	Programing techniques.	5 weeks
Steel plant				
Dispatchers	4	Classroom	Computer system and usage onsite.	4 hours
Systems engineers	4	Classroom	Basic programing.	2 weeks
Electrical engineers	2	Classroom and workshop	Programing maintenance.	10 weeks
Steel plant				
Electronics foreman	1	On-the-job	Computer terminology; location and function of hardware components.	5-7 weeks
		Classroom	Information entry and retrieval; machanics of peripheral equipment.	2 days
Electronics repairmen	12	On-the-job	Minimal training for minor maintenance given jointly with electronics foreman.	Ad hoc basis
Console operators	5	On-the-job	Use of computer to control mill setting and produce reports. Modifying and testing programs.	3 months
Steel plant				
Coordinator of control computers	1	Classroom	Familiarization with program prepared by vendor.	5 weeks
		Classroom	Familiarization with program prepared by vendor onsite.	1 week
		Classroom	Programing for business data processing computer.	Not provided
Procedures analyst	1	Classroom	Familiarization with program prepared by vendor.	5 weeks
		Classroom	Programing for business data processing computer.	Not provided
		Classroom	Equipment wiring procedures.	2 months
Electronics maintenance foreman	1	Classroom	Computer logic and maintenance onsite.	6 months
		Classroom	Programing onsite and at vendor facility.	3 months
Electronics repairmen	2	Classroom and on-the-job	Computer concepts, logic, and capabilities.	Class: 15 hours OJT: Periodically
		Classroom and on-the-job	Programing; functions of computer equipment; computer logic, etc., onsite.	Class: 1 week OJT: Periodically
Electric power plant				
Senior design engineers	7	Classroom	Various courses including computer concepts, programing, computer installation and checkout, and computer hardware.	2-12 weeks

See footnote at end of table.

Table 19. Training provided by computer manufacturers[1]—Continued

Recipient(s) of training	Number trained	Type of training	Description of training	Length of training
Electric power plant—Continued				
Assistant test engineer	1	Classroom	Hardware and programing.	12 weeks
Electronic technicians	2	Classroom	Maintenance and some programing.	8-12 weeks
Electric power plant				
Electrical engineers	13	Classroom	General orientation, programing, and maintenance.	1-3 weeks
Performance supervisor	1	On-the-job	Employee worked with vendor personnel assigned to program computer.	3-6 weeks
Technical foremen...........	2	Classroom	General orientation.	2 weeks
Operator supervisors	4	Classroom	General orientation	3 weeks
Operators and technicians	26	Classroom	Vendor participated in familiarization lecture program with user and equipment manufacturers onsite.	80-120 hours

1 Provided at vendor facility unless otherwise noted.

Course prerequisites. Requirements for enrollment in courses vary among vendor schools. For programing courses, an engineering or science degree generally is desired, although one school accepts students with a background in high school algebra. For maintenance courses, a good understanding of basic electronics and the ability to think logically are the basic requirements. The knowledge of basic electronics usually was acquired as a result of having an electrical engineering degree, formal training in electronics, or on-the-job experience.

Training Provided by Users

All but one of the survey plants provided employee training during conversion to computer control. The exception was a steel mill which relied exclusively on vendor staff for training. (See table 21.) The extent and kind of training were determined largely by a company's computer system requirements, its capability to provide training, and the type of training provided by the computer vendor. A total of 484 employees at survey plants received some form of classroom or on-the-job instruction.

Operators. Almost all training provided to operators at survey plants was given by company personnel, who usually had been trained by the vendor. The focus of training was on the operating procedures for the computerized system. The training was relatively brief, ranging from 4 to 80 hours, although sometimes this training was extended over a long period of time. Although most training sessions were held on-the-job, some involved classroom instruction.

Technicians. Most technicians also received their training from the user staff. The time spent in training varied greatly, largely because of differing job requirements for technicians among survey plants. Instrument maintenance men at a paper mill, for example, received 2 weeks of classroom instruction, whereas those with the same job title at a petroleum refinery were given 300 hours of on-the-job training. Two technicians at a chemical plant were trained for programing maintenance, one for 6 months and the other (jointly with vendor staff) for a year.

Supervisors. Several plants also provided training, including both computer orientation sessions and specialized instruction to supervisory and professional personnel. At a paper mill, for example, company staff joined with vendor representatives to familiarize the computer project group with the functions and programing of the planned computer installation; at a chemical plant, 10 chemical engineers were given 7 months training in programing.

Type of instructors, facilities, and methods. Training instructors from plant staff included engineers with a knowledge of computer programing, maintenance, and technology, and production supervisors who had undergone training either at their plants or at vendor schools. Training aids were used extensively to facilitate both classroom and on-the-job instruction. These included blackboards, manuals prepared by both the user and vendor staff, and, at one plant, a console mockup and templates which fitted over the dials of the operator console. At a papermill, a taped series of closed—circuit TV lectures on digital computers is being prepared for presentation to selected plant employee groups.

Table 20. Selected courses offered by the training school of a large vendor of process control computers

Title of course	Content of course	Prerequisites	Length of course
Process computer concepts	Fundamentals of digital computers and their place in automatic control, introduction to process computer programing, and descriptions of typical systems.	Interest in process computers.	2 days
Programing courses:			
Standard programing course	Computer concepts, number systems, flow charting, FORTRAN, and computer process assembly language.	Bachelor's degree in science or engineering and a working knowledge of process to be monitored or controlled.	4 weeks
Audio taped programing course	Specially prepared audio tape lectures and accompanying workbooks. (Can be taken at customer's locations and may be supplemented by 2 weeks "live" course at computer school.)	Bachelor's degree in science or engineering and a working knowledge of process to be monitored or controlled.	Determined by student
Maintenance courses:			
Programed instruction course	Number systems, digital computer theory, core memory theory, and basic machine-language programing. (Designed to prepare students for maintenance courses taught at computer school.)	Electrical engineering degree or 2 years of formal electronic training, plus 2 years' maintenance of major electronic equipment.	1 week (approximate)
Central processor maintenance	Detailed theory of operation of the computer system. Study and practice of preventive and corrective maintenance procedures.	Successful completion of examination covering material contained in programed instruction course.	11 weeks
Basic peripheral maintenance	Extensive theory and practical work on peripheral devices.	Successful completion of control processor maintenance course.	2 weeks
Disc memory maintenance	Theory of operation of the device and preventive and corrective maintenance procedures.	Same	3 weeks
Teletype printer maintenance	Same	Same	2 weeks
Card reader and card punch maintenance	Same	Same	1 week
Line printer maintenance	Same	Same	1 week
Remote scanner maintenance	Same	Same	2 weeks

SOURCE: Training brochures of computer vendor.

Table 21. Training provided by user companies

Recipient(s) of training	Number trained	Type of training	Description of training	Length of training
Papermill				
Task force employees (See table 24)	16	Classroom	(See table 24.)	2 weeks
Paper machine crews	35	On-the-job	Instrument functions and capabilities.	6 hours
Instrument maintenance men	33	Classroom	Instrument maintenance.	2 weeks
Chemical plant				
Instrument technician	1	On-the-job	Computer and instrument maintenance.	Periodic
Plant superintendent	1	On-the-job	Computer technology. Use of computer technology.	Periodic
Cracker operators	4	On-the-job	Operating techniques.	Periodic
Clerk	1	On-the-job	Computational techniques. Use of input-output equipment.	Periodic
Operators	4	On-the-job	Plant operation using computer.	8 hours
Process engineers	2	On-the-job	Computer system familiarization; programing.	4 months
Clerks; operators	30	On-the-job	Operation of computerized system.	
Chemical plant				
Chemical engineers	10	Classroom and on-the-job	Programing.	7 months
Programing technician	1	Classroom and on-the-job	Programing.	6 months
Program maintenance technician	1	Classroom and on-the-job	Programing and computer techniques, jointly with vendor.	1 year
Laboratory technicians	2	On-the-job	Computer applications to lab operations.	50 hours
Laboratory analysts	50	Classroom and on-the-job	Computer utilization.	16 hours
Chemical plant				
Operators	32	On-the-job	Operations of computer equipment.	Periodic
Operators	32	Classroom and on-the-job	Operations of computer eqiipment.	12 hours
Petroleum refinery				
Foreman, stillmen, operators	30	Classroom and on-the-job	Computer programs and operations.	40 hours
Foremen, stillmen, operators	25-30	Classroom and on-the-job	Computer programs and operations.	12 hours
Petroleum refinery				
Stillmen and controlmen	72	On-the-job	Operating techniques.	80 hours
Instrument man	1	On-the-job	Computer and instrument maintenance.	150 hours
Instrument engineer	1	On-the-job	Instrument maintenance.	300 hours
Instrument men	3	On-the-job	Instrument maintenance.	300 hours
Steel mill				
Melter foreman, operators, and helpers	50	Classroom	Basic operating procedures.	4 hours

Table 21. Training provided by user companies—Continued

Recipient(s) of training	Number trained	Type of training	Description of training	Length of training
Steel mill				
Electronics repairmen	12	On-the-job	Minor maintenance of computer system jointly with vendor staff.	Periodic
Electric power plant				
Operators	29	On-the-job	Operating procedures.	-
Control group engineers	2	On-the-job	Programing.	3 weeks
Electric power plant				
Operators and technicians	26	Classroom	Familiarization lectures jointly with computer and equipment vendors.	16-24 hours
Cement plant				
Kiln burners	3	On-the-job	Basic operating procedures.	-

Training has been formalized at many survey plants, some of which maintain permanent programs for developing employee skills. One large chemical plant, for example, has a continuing program that consists of three sequential courses. The basic course consists of mathematics, process flow, and chemical technology, which is followed by two advanced courses pertaining to plant operations and process technology. After completing the two advanced courses, employees receive a pay increase.

Training generally was provided during working hours. In at least two survey plants, however, training sessions were conducted after regular working hours, and the trainees earned overtime pay.

As plants gain experience in computer process control, evidence from this study suggests they will rely increasingly on their own staffs for the training of new personnel in computer tasks. The two newest engineers at an electric power plant, for instance, were assimilated into the control group with only 3 weeks' training that consisted of reading a programing manual and experimenting with control problems. This power company believes that outside training for this control group will not be necessary as long as it maintains an experienced group of engineers.

Training Provided by Educational Institutions and Other Groups

As a general rule, technical schools and colleges were not found to be important sources of training for computer process control. A cement plant included in the survey, however, sent four electricians to a local junior college at its expense for 16 weeks' instruction in electronics to prepare them for work as instrumentation technicians.

Technical schools and junior colleges may be used more extensively as their curriculums are broadened to meet the needs of companies in process industries. The major training tasks of these institutions, however, probably will be to provide the necessary skills needed to qualify for entry positions as technicians and operators. An important source of training for managers and technical personnel will continue to be the relatively brief (often 1 to 2 weeks in duration) courses in computer concepts and techniques which are offered by universities, industry technical associations, and private consulting firms.

Schools also have been established for the development of computer technicians by some computer manufacturers. Computer technology (40 weeks) and programing (20 weeks) are among the courses offered at one of these schools. A high school education or its equivalent is required for entrance.

Some experts foresee that training of engineers, systems analysts, and related technical staff involved in implementing computer process control may increasingly involve postgraduate instruction, since presently most undergraduate curriculums do not include some essential specialized technical subjects related to computer control. It is significant, however, that a few schools reportedly have initiated undergraduate BS degree programs and others now offer selected courses in the field of systems engineering. Some idea of the educational requirements for computer process control is indicated in appendix B-4, which lists some of the suggested courses for process control systems engineers in the chemical and petroleum industries. With slight modification, this list would be appropriate for process computer applications, regardless of industry.

Criteria and Methods of Selecting Employees for Training

Employees who received training as a result of the conversions to computer control included those in existing jobs whose duties were to be affected by the introduction of the computer, and those assigned to the new programing, maintenance, and operating tasks created by the computer. Employees in the first group, primarily operating personnel and their supervisors, automatically received the training needed to perform their duties under the modified operating conditions. The latter group comprised employees selected for new positions and others assigned from engineering staffs to work in computer occupations.

Selection criteria most frequently considered by survey plants for computer-related training assignments included work experience, ability, interest, and aptitude. Job performance and amount and kind of education also were considered. In addition, work experience and knowledge of a given process were cited by several companies as important reasons for recruiting programer trainees from within the company.

Particular personal temperaments and aptitudes were looked for by various companies in screening applicants for training. Those most often cited were dedication, initiative, patience, persistence, adaptability, capacity for logical thinking, and interest in pursuing education.

Methods used by plants to appraise qualifications for training ranged from management judgment of employees' records to reliance on standard aptitude tests. Both tests and interviews were employed in several plants to screen candidates. Seniority lists were used at one plant to select instrument men for training in computer maintenance from among employees who had completed outside courses in electronics.

A high school diploma represents the preferred minimum educational requirement for operator and technician jobs. Applicants for technician jobs at a power plant, however, were required to have 2 years of technical school training in mathematics and electronics. Moreover, officials at several plants expressed a preference for applicants with technical training equivalent to the junior college level for operator jobs.

Appraisal of Training

Although few problems involving training were reported, officials at all survey plants expressed a need for greater preparatory training for work with computer control. Some courses considered useful are presented in table 22. The desirability of a more thorough preparation in mathematics and the physical sciences in high school was mentioned repeatedly. The importance of technical schools and junior colleges in providing instruction in these subject areas and in electronics also was stressed.

Table 22. Type of courses for computer process control desired by officials at selected survey plants

Plant	Suggested courses
Papermill	Education oriented toward the development of logical thinking would be desirable, including high school courses in geometry and algebra.
Chemical plant	More high school training in mathematics is needed for operators. Junior colleges are beginning to offer 2-year courses in processing technology, and a graduate of such a course would be preferred to a high school graduate for operator jobs.
Cement plant	More formal education in electronics, instrumentation, and mathematics would be useful in preparing operating employees for computer control.
Steel mill	Technical school training, courses in mathematics, and electrical training would be helpful in preparing operating employees for computer control.
Electric power plant	Technicians, technical assistants, and helpers should have a high school education, with courses in physics, chemistry, and electronics. Training courses offered by the computer manufacturer will continue to be used for systems engineers and programers.
Electric power plant	Courses useful for computer process control engineers include Boolean algebra, basic to logical thinking and to understanding computers; discrete sampling techniques; linear programing; and digital techniques for solution of practical differential equations.

CHAPTER 10. LABOR–MANAGEMENT ADJUSTMENTS

The introduction of process computers has caused minimal adverse manpower impact at most survey plants and has resulted in only a few major problems affecting labor-management relations. Most of the survey plants had existing collective bargaining contracts which contained provisions to facilitate the adjustment of workers to technological change. These provisons provide the mechanism for giving advance notice, setting wage rates, reassigning workers, and providing benefits for workers laid off.

Contract Provisions Relating to Technological Change

Workers were represented by unions at 9 of 12 plants visited. Major unions at survey plants are the Oil, Chemical and Atomic Workers International Union; the International Brotherhood of Electrical Workers; the United Steelworkers of America; the International Union of Pulp, Sulphite and Paper Mill Workers; the International Union, District 50, United Mine Workers of America; and the Independent Petroleum Workers of America.

All of the collective bargaining contracts at the survey plants have broad general provisions that protect workers affected by technological change. These provisions cover topics such as job security, advance notice of technological and other changes, displacement and downgrading, procedures for manning new jobs, severance pay, and layoff benefit plans. In a few plants, contracts contain a clause that ensures the use of these provisions in instances of technological change. The following are examples of two such union contract provisions at a survey chemical plant.

> The collective bargaining contract contains a statement of intent pertaining to job security. Its purpose is to minimize "....adverse effects on employees...elimination or downgrading of jobs arising from automation, restructuring of work, and operations improvement.." The company is obligated to "...inform employees directly affected when changes or improvements are proposed and are to be studied, as soon as such advance information may be feasible, and in any case before the proposals are instituted..." Workers affected by the three process control computer installations at this survey plant were notified well in advance of the changes.
>
> A formal job evaluation plan provided for in the union agreement was used to adjust the wage rates of workers affected by process computers. Job evaluations were requested by the union for eight operators working in two of the units using computer control. Factors such as skill, physical and mental demand, working conditions, and responsibility for equipment, product, and materials were assigned a number of points depending upon their relative importance. The point total for each job category was agreed upon by union and management representatives and was used to set the wage rate. As a result of these job evaluation studies, four operators received an increase in wages, but the other four operators retained their former rate.

Informing Employees About Change

Employees in the affected units were notified in advance of the actual installation of the process computer system at 10 of the 12 plants visited. The period of advance notice ranged from 4 months to 2 years at survey plants. The most usual way of informing workers about the pending installation of computer process control was a special meeting held by supervisors with workers in the affected unit. Other communication techniques included a description of the forthcoming change in the company newspaper or bulletin, discussions during regular union-management meetings, notification of the union by letter, and notification through the local press to the public.

Prior to the installation of the computer, a description of the system was provided the workers, and its probable effect on their employment was discussed with them. In a paper plant, for example, the possibility that workers might be displaced and the changes in job content of workers in the affected unit were the subjects discussed at a meeting of company and union representatives. Other topics of discussion between company and worker representatives at survey plants were training programs and job evaluation studies for affected workers.

Special Negotiations and Grievances

Union-management negotiations or specific grievances related to the introduction of process computers occurred in only two plants. At a petroleum refinery, one of the unions became concerned about who would have jurisdiction over the maintenance of the process control computer that was to be installed. The union brought this matter up during a regular union-management meeting and indicated that union members were qualified and should maintain the computer. The company's position was that it had a contract with the computer manufacturer for maintenance of the computer. The result of the negotations was that union members would repair minor difficulties, and the manufacturer's representative would be called to repair major equipment malfunctions.

At a power plant, formal grievances were filed concerning the abolition of two extra operator jobs per shift in a new plant using a process computer. A specific grievance was filed for each job abolished. These jobs were added to the operating crew of the plant to assist with additional tasks required during the shakedown period when the plant was being brought into operation. Following past procedure, the company wanted to abolish the extra jobs after the shakedown period was over. The union's position in contesting the job reductions was that the computerized plant could not be operated safely without the additional workers. A major union complaint was that the workers in the contested jobs were needed to check out the numerous alarms about plant operations given by the computer. The arbitrator, however, ruled in favor of the company on both jobs and they were abolished. Employees in these abolished jobs were transferred to other positions.

Union Comments About Computer Process Control

The effects of the introduction of process control computers on workers were discussed with local union representatives at the nine unionized plants visited. Since the majority of the survey plants were already highly instrumented, process computers were felt to be merely a further extension of instrumentation for use in control over plant processes. Such changes had been introduced frequently in these plants in the past, and the union officials accepted these changes as part of the technological evolution of the industry. Most union officials indicated that worker adaptation to computer process control created no serious problems. In some cases, union representatives felt more concern about other kinds of technological changes that might have a greater effect on employment at their plants. At steel mills, for example, the basic oxygen furnaces being introduced are expected to have a greater effect upon workers than computer process control.

A number of officials, however, felt that adverse effects upon union members were possible in the future. At two petroleum refineries, for example, the increasing use of process computers is expected to accelerate the declining employment of operators and maintenance workers. At one electric power plant, computer process control is expected to reinforce the adverse effect on the work force brought about by other recent technological changes. At another electric power plant, more automatic computer control operations may lead to future reductions in manpower. (See appendix B-5 for more extensive comments by union representatives about the introduction of process computers at specific survey plants.)

CHAPTER 11. OUTLOOK FOR COMPUTER PROCESS CONTROL AND MANPOWER

Process computer installations are expected to increase greatly in number and complexity over the next decade, and probably will result in significant increases in employment of engineers, programers, and technicians. However, fewer operators may be needed as computer control is improved and centralized further.

Growth in Number of Computer Control Installations

Continued growth in the total number of process control computer installations is expected though the future growth rate is difficult to estimate because of diverse factors such as changing computer technology, the expansion of process computer applications to many areas outside of process industries, the economic conditions in the industries involved, and the changing economic conditions of the Nation. From 1963, the first year that a significant number of process computers were reported, to 1968, process computer installations in the United States have been increasing at an average annual rate of 48 percent, and worldwide at an average annual rate of 55 percent. Although these rates may not be sustained, a continued high rate of growth can be expected. Some industry experts suggest that the increase in process computer installations may be about 20 percent a year in the near future. Projecting the 1968 estimated total of 1,647 process computers in the U.S. and 3,094 in the world at this 20 percent rate to 1975 results in totals of about 5,900 U.S. and 11,100 worldwide installations.

Outlook for computer control in process industries. Most experts at survey plants foresee expansion in the number of computers and the ways they will be applied in the process industries. The paper industry will be using process computers for control of nearly all major processes by 1975. In the chemical industry, officials interviewed estimated that all large chemical plants and 90 percent of the major production processes will be using process computers by 1975. In addition, all petroleum refineries with capacities of 50,000 barrels a day and all major refining processes should be using some form of digital process computer control by the mid-1970's. Laboratory computer systems are expected to become important in both the chemical and petroleum refining industries. The key steps of raw materials blending and kiln control in the cement industry are expected to account for the largest number of future applications. By the early 1970's, in the iron and steel industry, all new hot strip mills and basic oxygen furnaces are expected to be using process computers. Continuous casting also is expected to be a prime candidate for computer control. Main applications of process computers in the electric power industry will be for startup, shutdown, normal operations and performance calculations for conventional plants, and economic dispatch for power systems. Nuclear plants also probably will be computer controlled. An increase in process computer installations is expected in many sectors of the economy outside of the process industries. Specific forecasts of future installations and applications by officials at survey plants are presented in appendix B-6.

Factors Affecting Outlook for Computer Process Control

Changes in process computer control technology and programing techniques are expected to be a particularly important determinant of growth in the number of process computer installations and the type and scope of application in the near future. Specific factors affecting the future of computer process control mentioned by officials at survey plants are presented in appendix B-7.

Two trends in computer equipment are underway. One trend is toward small, relatively low cost computers which are economically feasible for control of a single small process, or if used in multiples, for control of a large process. The other trend is toward large, expensive computers with time sharing, priority interrupt features. At present the calculating power of these large computers is such that many complex processes in a plant can be run by a single unit. Systems are being set up with the computer in a central location. By using data transmission lines, many plant processes can be placed under continuous control. Time sharing capabilities of these computer systems allow a number of different type process operations to be interwoven into their operating functions, and it is expected that this type of computer system will have even greater capability in the future.

Both of these trends are leading to lower cost computer control operations. Small computers will allow applications in areas that were previously uneconomical; large computers will lower the cost of control over individual processes in a large plant. In addition, the growing production of process computers and continuing competition among computer manufacturers also are leading to decreased computer costs. In a paper plant visited, for example, a process computer installed in December 1962 was leased for $14,000 a month. A replacement computer installed in January 1967, however, cost only $7,000 a month, despite the fact that it has 10 times the computing capability of the former unit.

Computer reliability also has increased greatly since process computers were introduced. As reliability of equipment increases, more dependence will be placed on the computer system and less on human control.

New and more advanced instrumentation, including more accurate on-line analyzers, are being developed for process control. Much emphasis is being placed by instrument manufacturers on making equipment compatible with computer control. These trends are expected to lead to more precise control, and the ability to operate the process closer to equipment limits.

Direct digital control has proved successful and can be expected to increase in application in the future. One of the major advantages of DDC is that the conventional analog controllers, used for most existing process control applications, are replaced by a digital computer connected directly to the process. Some of the gains are a reduction in the cost of large projects, improvement in control performance, and greater flexibility in changing control strategy. DDC is expected to have its greatest use in new plants where the control systems can be designed specifically for this advanced technique rather than in existing plants which already have analog controllers installed. Use of DDC for control of batch processes probably will lead to increased process computer applications in many industries.

The use of computer hierarchy systems, consisting of interconnected computers at different levels of a plant or a company, is expected to increase in the future. A small number of these systems are planned or in use at present, and the early stages of such a system were observed at a survey paper plant and a petroleum refinery. Many of the operating decisions of a large multiprocess plant, or a complete company, could be assumed by a computer hierarchy system. DDC can be expected to find a major application in such systems.

Specialized computer languages designed to assist engineers in programing for process control applications are being developed. These languages will relieve the programer from directly writing machine instructions and will allow him to set up a program package with the best operating procedures for the computer system being used with a minimum of effort.

In addition, a number of standardized program packages for process control applications have been developed by computer manufacturers and by firms that anticipate many process computer applications. They consist of a set of general programs that can be modified easily to fit individual control projects and are designed to be used by engineers with a minimum of computer training. Much of the cost, time, and effort of programing will be reduced by the use of these standardized programs.

Another recent and important development has been the licensing of standardized process models for commonly used industrial processes. Process models for catalytic cracking have been developed, for example, that can be used by units at different locations with a minimum of adjustment.

Outlook for Employment and Occupations in Process Industries

Employment trends are expected to vary in the different process industries surveyed because of factors such as changes in general economic conditions, productivity, demand, and technology, including computer process control. In three industries––pulp and paper, industrial chemicals, and iron and steel––employment is expected to increase slightly; in two––petroleum refining and hydraulic cement––employment is expected to decline slightly; in the remaining industry––electric power––little or no change in employment is anticipated. Employment in total manufacturing, on the other hand, is expected to increase gradually through the 1970's.

Prospects for major occupations affected by computer control. An increased demand for systems, control, instrument, and process engineers can be expected because of the growing emphasis on advanced control techniques and equipment and the expanding output in the process industries. The expanding number of process computer installations and applications is expected to be a key factor in accelerating the demand for these highly skilled engineers who will be needed to plan, develop, install, and repair computer equipment and instrumentation. This trend can be expected to continue despite factors such as growing experience in process computer technology and the introduction of standardized process models, which serve to reduce engineering effort. (Specific occupational trends forecast by officials at survey plants are presented in table 23.)

Employment opportunities for programers in the process industries also are expected to increase, but not as rapidly as for engineers. This is due in part to the practice of training engineers to perform programing tasks for process computers and the increasing use of standardized program packages. More programing technicians and assistants also will continue to be needed to update and maintain computer programs. Demand for process computer programers can be expected to increase in firms outside of the process industries, such as computer manufacturers and consulting firms who are expected to continue to supply much of the programing effort needed for process computer installations.

The demand for operators in the process industries is expected to continue to decline, due mainly to the continuing shift to large capacity production units, centralized control rooms, and more automatic controls. This decline in demand for operators is likely to be reinforced by the growing use of process computers. Older plants may centralize control rooms at the same time as they introduce computer control, thereby reducing the need for operators. New plants, designed and built to encompass computer control, probably will require fewer operators than similar plants without computers. However, electronic and instrument technicians, who are needed to install and repair complex computer equipment and sophisticated electronic instrumentation, can be expected to increase in number.

Other types of occupations also are expected to be affected by computer control. Demand for laboratory analysts in analytical and production control laboratories, for example, may be reduced by the increasing use of computer systems for routine analysis and calculations. Employment of record and production accounting clerks also may be reduced, since much of the data logging and report preparation done by these workers can be carried out automatically by process computers.

Multiprocess, plant, and company control, advanced forms of computer control that are now receiving much emphasis, may have adverse manpower implications in the future. A complete plant, for example, could be operated with a crew no greater in size than is presently required to operate a single control room; this situation obviously would result in a significant decrease in operating manpower.

Table 23. Outlook for further occupational changes at selected survey plants because of computer process control

Survey plant	Outlook
Papermill	As paper machines come increasingly under computer control, the duties presently performed by crews will be reduced. Possibly within 10 years, a single crew, perhaps larger than a current single crew today, will be able to operate 2 paper machines. Within 10 years, less labor probably will be required in the operations of threading the machine, changing paper grades, and cleaning the machines than at present. The quality control capability of the computer probably will eliminate the present occupations involved with testing and inspection. Also, instrument maintenance will become much more systematic and demand a higher level of technical skill.
Chemical plant	Labor costs as a percentage of total costs in large chemical plants are very low. Emphasis, therefore, is on improving control and reducing raw material costs rather than reducing manpower requirements. In analytical laboratories, labor costs are the largest expense. Consequently, use of computers is expected to have a great impact on manpower in laboratories. Computers in the analytical control labs will affect both supervisors and technicians. Through the use of computer systems which include data transmission lines and remote chromatograph stations, laboratories may be able to double present loads. Although this chemical plant does not yet have a permanent computer control group for systems design and programing, it probably will have one in the future because applications are growing so rapidly that the company cannot afford the loss of programing skills and computer knowledge which occurs when computer project groups breakup.
Chemical plant	The size of the computer systems engineering group is expected to increase from 3 to between 6 and 9 workers, including systems engineers, programers, and technicians. Computer systems, however, are not expected to have much impact on the employment of operating personnel since operators will be employed to assure operation of the plant during emergencies with which the computer cannot cope. Training of programers and technicians will become more important, since the adverse effects of lack of training in computer technology only are beginning to be felt. The shortage of trained process computer personnel is likely to retard more widespread use of computer process control in the petrochemical industry.
Petroleum refinery	Most units at this refinery have been utilizing automatic controllers for some time; therefore, the operating staff is small and not much change is anticipated. Maintenance employment, which has been declining due to a continuing consolidation of small units into larger and more efficient ones, is expected to continue to decline slightly because of the utilization of computers which allows equipment to operate for longer periods between shutdowns for maintenance. The computer applications group is not expected to grow much larger. If more technical manpower is needed, the companies' policy will continue to be to borrow personnel from other parts of the corporation to work on specific projects. Lack of qualified technical manpower for new key positions is a fairly universal problem. For the industry as a whole, more process engineers with chemical engineering backgrounds and computer knowledge will be needed. Standardized process computer programs, however, could reduce the need for programers.
Petroleum refinery	The company can foresee complete automatic control in the future. Such installations would have a computer in complete control of all process operations. The operator would remain only as a monitor. If this plant is to increase utilization of process computers, however, it needs more skilled programers and instrument men who are trained in electronics.
Steel mill	Engineers and maintenance workers will need to acquire some knowledge of computer control systems and the capabilities and methods to maintain them. More maintenance workers and systems engineers will be needed. Additional programing skills also may be required.
Steel mill	Further use of process control computers is not expected to lead to any notable labor displacement. Operators will continue to be needed at least as backup men to run production processes manually in the event of computer system failure. More maintenance personnel may be required, and maintenance job skills will have to be extended and upgraded.
Electric power plant	The amount of time spent calculating performance requirements and testing is expected to be reduced because of computer control.
Electric power plant	Nuclear power plants may tend to decrease the number of plant personnel due to increased automation, including computer process control, less maintenance, and elimination of coal handling. Skill levels in nuclear plants probably will be higher.

SOURCE: Based on interviews with officials at 9 survey plants.

APPENDIX A. SCOPE AND METHOD

Coverage of Survey

This study is limited to the use of digital process control computers in the highly instrumented process industries where computer control was first adopted beginning in the late 1950's. Twelve plants in six major process industries were visited by BLS staff for information for the study. These industries are paper, industrial chemicals, petroleum refining, hydraulic cement, iron and steel, and electric power. Table A provides detail on the number of plants, process control computers, and employees in the survey. A total of 28 separate process control computer installations were surveyed.

Plants included in the survey varied in size from several hundred employees at an electric power station to nearly 19,000 employees at a large steel mill. Total employment at the time of visit in the operating units where process computers were introduced was 1,644––about 3 percent of the total employment of 63,687 at these plants.

Survey plants were located in 10 different States in the East, South, and Midwest. Most plants were in or near major population centers. However, several were in communities with fewer than 50,000 people.

Method

The first phase of research involved a comprehensive review of trade journals, technical magazines and books, corporate annual reports, and other secondary source materials to determine in which industries process control computers were being applied. Articles describing specific plant installations were helpful in selecting representative and illustrative plants to include in the field survey. A listing of secondary source material is included in the bibliography.

Next, the major producers of process control computers were visited by BLS staff to discuss in depth the outlook and implications of computer procees control. Company technical staff provided expert judgment on the possible future rate of adoption of computer process control in the various industries and applications. Prospects for further refinements and advancements in computer technology also were discussed. The brochures describing the various systems obtained during the visits were helpful in acquiring a better understanding of the capability and functions of computer process control systems.

The next step was to select the plants to be included in the study. Substantial effort was made to include plants in the major process industries which would be representative of processes being put under computer control. Twelve plants in six major process industries were selected for study on the basis of the secondary sources described above and interviews with experts. These 12 plants represent a wide range of applications and levels of computer control. Only plants with systems in operation for at least 1 year were included in the survey so that effects on employment could be examined more readily. Plants also were chosen that had replaced early process control systems with more advanced systems. Most plants contacted had more than one computer system functioning when visited.

A questionnaire was developed for use as an aid in gathering data during informal discussions with management and union officials. The prior steps of reviewing secondary source materials and visits to computer manufacturers were very helpful in developing a draft form. This questionnaire was reviewed by government, industry, and labor experts, and their suggested revisions were incorporated.

The plant visits were undertaken by BLS staff who spent an average of about 2 days at each plant interviewing company officials who had direct knowledge of the installation. Administrators, managers of production units, industrial relations experts, engineers, computer technicians, and maintenance staff were among typical company employees interviewed. In addition, the local officials of the unions representing the employees at the plants were interviewed. Information was obtained on topics such as the nature of the computer control system and process application, reasons for installation and economic benefits that resulted, extent of worker displacement and reassignment, characteristics of employees in jobs created and abolished, and training programs and other techniques to prepare employees for new duties relating to computer process control systems.

Table A-1. Number of survey plants, process control computers, and employees in operating units with process control computers

Process industry	SIC code[1]	Number of plants in survey	Number of process control computers covered in survey	Total number of employees in operating units with process control computers
Pulp, paper, and board	261,262,263,266	1	1	35
Industrial chemicals[2]	281	3	12	[3] 220
Petroleum refining	291	2	4	38
Hydraulic cement	324	1	1	17
Iron and steel[4]	331	3	6	[3] 669
Electric power	491,493	2	[5] 4	665
Total		12	28	1,644

1 U.S. Bureau of the Budget, *Standard Industrial Classification Manual, 1967.*
2 Includes inorganic and organic chemicals.
3 Employment for some units unavailable and therefore not included in total.
4 Blast furnaces, steelworks, and rolling mills.
5 Includes two computers in survey plants and two in other plants of companies surveyed for whom extensive data were obtained.

A draft report was prepared based primarily on data obtained during these field visits, supplemented by analysis of government statistics, trade and technical publications, and other secondary sources. It then was sent to company and union officials, industry and government experts, technical journal editors, and others for comment on the validity and accuracy of findings. Their suggested changes were evaluated and the necessary revisions incorporated.

Limitations

In assessing the results of this study, consideration of several limitations is important.

First, not all applications of computer process control were covered. This study focuses on the use of computers to control operations in process industries and does not cover their limited but growing use in discrete product manufacturing industries for functions such as industrial testing and production control. Process computers used in research, educational, or medical institutions are not covered by the survey. The study also excludes analog computers which are being used for control applications involving only a few variables.

Second, the study focuses on the manpower and economic effects of computer process control at user plants only. Indirect effects on manpower at plants where computers are manufactured were outside the scope of the study. Also excluded was an evaluation of possible employment and other manpower problems at competing plants which had not yet adopted digital process control computers.

Third, data on certain aspects of the study, such as on the type and extent of manpower and economic savings, were classified as confidential by a few companies and therefore were unavailable.

Finally, the experiences of plants included in the study may not be representative of the manpower impacts that might occur at a later stage of use of process control computers when advanced types are developed and installed.

APPENDIX B. TABLES

(Tables B-1 through B-7.)

Table B-1. Employment, output, and output per man-hour, in manufacturing and major process industries, selected years, 1957-69

Industry	SIC code[1]	Employment: Number of employees 1969 annual average (in thousands)		Employment: Average annual percent change 1957-69[2]		Output and output per man-hour: Average annual percent change 1957-68[2]		
		Total	Production workers	Total	Production workers	Output	Output per man-hour: All employees	Output per man-hour: Production workers
Manufacturing	-	20,121	14,735	1.8	1.5	[3] 5.4	[3] 3.4	-
Pulp, paper, and board	261,262, 263,266	297.8	233.0	[4] .2	[4] -.2	[5] 5.1	[5] 4.7	[5] 5.0
Industrial chemicals	281	314.2	172.8	[4] 1.3	[4] .5	[6] 10.2	-	-
Petroleum refining	291	146.3	86.1	-2.5	-3.3	[5] 3.2	[5] 7.2	[5] 7.4
Hydraulic cement	324	35.1	26.9	-2.1	-2.9	[5] 2.1	[5] 4.8	[5] 5.5
Iron and steel[7]	331	643.9	513.8	.1	-.1	3.1	2.6	2.6
Electric power and gas[8]	491,492, 493	616.1	529.0	.4	0	7.0	6.5	6.9

1 U.S. Bureau of the Budget, *Standard Industrial Classification Manual, 1967.*
2 Based on the linear least squares trends of the logarithms of the index number.
3 Output is gross product originating and is not strictly comparable with output and output per all employee man-hour measures for individual industries.
4 Rates are for period 1958-69.
5 Rates are for period 1957-67.
6 Federal Reserve Board. Not strictly comparable with output measures for manufacturing and other process industries.
7 Blast furnaces, steel works, and rolling and finishing mills.
8 Not strictly comparable with definition of survey industry used elsewhere in the report. Includes SIC 492, gas companies and systems.

SOURCE: Average annual percent change in output for industrial chemicals is based on Federal Reserve Board data. All other data are from U.S. Department of Labor, Bureau of Labor Statistics.

Table B-2. Major applications of process control computers in survey industries in the United States, July 1968[1]

Industries and applications	Number of applications
Electric power:	
Electric generating stations	199
Scan, log, and performance calculations	51
Nuclear plants	12
Operator guide control	11
Start, stop control	10
Power systems	43
Economic dispatch and load control	34
Industrial chemicals:	
Ethylene production	16
Analytical laboratory and chromatograph control	14
Ammonia production	6
Iron and Steel:	
Basic oxygen furnace	22
Electric arc furnace	19
Hot strip mill	18
Plate mill	7
Tinning line	6
Power demand	5
Blast furnace	4
Petroleum refining:	
Refinery control and optimization	17
Catalytic cracking	15
Gasoline blending	6
Crude distillation	4
Analytical laboratory and chromatograph control	4
Pulp, paper, and board:	
Papermaking machine	13
Hydraulic cement:	
Rotary kiln control	14
Cement blending	5

[1] Applications that were reported less than four times were excluded.

SOURCE: See footnote on table 2, p. 12.

Table B-3. Major job duties of three occupations in an 80-inch hot strip mill affected by process computer control

Job title	Primary function	Major duties
Recorder	To compile complete record of 80-inch mill operations.	Copies rolling schedule.[1] Checks charging tally for weight of material rolled.[1] Maintains hourly production report.[1] Compiles production data such as steel rolled, rolls changed, delays and runbacks.[1] Notifies concerned personnel on rolling schedule changes such as runbacks, cobbles, rejects, blow-out, etc.[1] Assists computer operator, as directed. Picks up charging tallies from order stocker and gives copies to coil marker and computer operators. Picks up and checks roll data card against record and delivers to roll shop. Picks up and delivers rolling schedule to concerned mill personnel. Maintains working area clean and orderly.
Assistant roller	To control settings for guides, loopers, and four finishing stands; assists roller and directs crew in mill set-up and roll changes.	Operates various controls to make necessary adjustments to mill and guide settings.[1] Operates controls for run-out table water spray.[1] Synchronizes speed for a section of run-out table.[1] Sets thickness and width gage indicators to order requirements and sets the decode system for automatic gage control.[1] Receives, records, and signals notice of last slab on order.[1] Operates controls for roll cooling system. Observes passage of strip for possible correction of mill screw down. Requests and/or makes necessary gage and width corrections. Directs the roll hand to make necessary mill stand adjustments. Directs and assists roll changes, mill adjustments, and removal of cobbles. Checks whether lubrication system light is on. Maintains equipment and work area clean and orderly.
Coiler operator	To operate table rolls, guides, pinch rolls, and coiler to coil strip steel.	Sets guides to proper width of strip.[1] Operates controls for coiler water sprays.[1] Operates stripper car and downender to deposit coils on conveyor.[1] Operates controls to synchronize table rolls, pinch rolls, and coiler speeds with mill delivery speed to insure proper coiling of strip. Works with mill crew to make roll changes, remove cobbles, and perform other miscellaneous operational functions. Turns on stop signal in event of trouble or as directed by Ganger. Checks whether lubrication system light is on. Maintains equipment and work area clean and orderly.

1 Performed automatically when mill is on computer control.

SOURCE: Plant records.

Table B-4. Suggested courses for process control systems engineers

Engineering management

Personnel supervision
Industrial organization
Elementary accounting
Evaluation of investments
Scheduling (PERT, CPM)
Contracts and specifications

Mathematics

Calculus
Differential equations
- Ordinary
- Partial

Operational calculus
Matrix Algebra
Numerical methods
Probability and statistics
Fourier Analysis
Optimization
- Linear programing
- Gradient methods
- Variational calculus
- Dynamic programing

Computer programing
- Analog
- Digital

Boolean (logical) algebra

Chemical engineering

Inorganic and organic chemistry
Stoichiometry
Material and energy balances

Chemical engineering—Continued

Mass and energy transfer
Thermodynamics
Reaction kinetics
Unit operations
Process dynamics
Instrumentation (measurements)

Control engineering

Basic control theory
- Time-domain analysis
- Frequency-domain analysis
- Stability
- Synthesis

Sample-data systems
Multivariable systems
Nonlinear systems
Adaptive systems

Electrical engineering

Network analysis
Field theory
Electronics
Logic devices

Other fields

System concepts
Economics
Operations research
Information theory
Psychology
Human engineering

SOURCE: T. M. Stout and J. H. Hiestand, *"Process Computers and Chemical Engineering Education."* Paper presented at the American Institute of Chemical Engineers, 61st Annual Meeting, Los Angeles, Calif., Dec. 1-5, 1968.

Table B-5. Union comments on computer process control at survey plants

Type of plant	Comments of union representatives
Paper plant	Unionized workers were not affected adversely by the introduction of the process computer. The computer provided increased jobs for nonunion workers such as programers and process engineers.
Chemical plant	The workers did not find adaptation to computer process control difficult, because a continual change in technology had taken place at this plant. The company job security plan offers valuable protection against displacement caused by technological change. No major problems related to computer process control are expected in the future.
Petroleum refinery	Workers selected to operate the computer controlled units did not find adjustment to the changed jobs difficult. However, they feared that as computer use increases an accelerated decline in maintenance workers will occur. Computer control allows units to operate closer to physical limits with less equipment breakdown and therefore less regularly scheduled shutdowns for maintenance. Moreover, marginal units, which cannot be computer controlled, are expected to be terminated and the operating and maintenance crews cut back.
Petroleum refinery	*Electrical workers union*—because the amount of plant instrumentation required for process control computers and other technologies has increased, the number of union members who install and maintain these instruments has risen, despite the general downtrend in total plant employment. Therefore, process computers are felt to be advantageous to union members. However, job classifications and wage rates for instrument men working on computerized units have remained unchanged, despite the union position that these workers require greater ability than those working on noncomputerized units. *Operating and maintenance workers union*—a major decline in the number of union members at this plant has taken place due to a continuing modernization program. The operating staff at the computerized units was cut back at about the time the computers became operational. This employment decline was attributable to the instrumentation needed for putting the units under computer control. An increasing number of process computers probably will be used to control older units at this plant. The instrumentation needed for these computers and the laborsaving potential of computer control are expected to lead to large reductions in operating and maintenance manpower.
Steel plant	New technologies, such as basic oxygen furnaces, will continue to have a substantially greater impact on manpower than installations of process control computers.
Steel plant	Employees adapted to computer process control with little difficulty. However, major changes in employment, occupations, and job skills are expected because of other innovations, such as continuous casting.
Steel plant	Worker adjustment to computer control presented no problems. More concern was felt about other innovations, such as the basic oxygen furnace.
Power company	Technological changes, such as automated substations and centralized controls, are expected to have more effect on the work force than process computers. However, computers are expected to accelerate the changes brought about by the other innovations.
Power company	Process computers are not expected to affect operating workers to any significant extent. However, innovations such as substation automation, plant automation, and interconnected switching systems are expected to have major impact upon union workers. Computer control over automatic startup and continuous operations of power plants may cause future reductions in employment.

SOURCE: Based on interviews with local union officials.

Table B-6. Outlook for installations and applications of computer process control at selected survey plants

Survey plant	Outlook
Paper company	The paper machine at the survey mill will be placed under a more advanced form of computer control. Other papermaking machines presently under conventional control in this mill also will be placed under computer control. Within the corporation, 14 major papermaking steps with potential for process computer applications were mentioned. Among these are the bleach plant, where computer control of primary bleaching may save $600 a day; batch and continuous pulping mills; electrical and steam distribution facilities; chemical recovery; paper and board machines; woodyards and woodrooms; and the finishing department. These applications are being studied by an outside consultant to set up a 3 to 5 year program of computer usage. If found to be technically and economically feasible, they could be placed under computer control by 1975. The company is in the process of setting up a computer-based planning and control system that will encompass all aspects of the company's operations—accounting, shipping, inventory, manufacturing, scheduling, and marketing. Data transmission lines will connect both general purpose and process computers in different company plants and areas to provide an integrated management control system.
Chemical plant	Applications of the computerized plantwide production control system will be increased to include more units and more advanced control techniques. A computer system to be installed in an analytical control laboratory will operate all chromatographs in the lab and at least one chromatograph station in an operating unit. Other laboratory instruments may be connected to the system. Based on a detailed feasibility study, the laboratory computer is expected to save $60,000 a year in labor and instrument costs and produce a major increase in speed and accuracy of analysis.
Chemical plant	An estimated 10 to 20 percent of major plant operations may be under full closed-loop control by 1975. The computer system in the analytical control laboratory has been successful, and its applications will be increased through further programing effort.
Petroleum refinery	A centralized computer control system, designed to replace the two existing control computer systems and control other major plant units, is being installed. This system may be connected, via data transmission lines, to a large scale computer at company headquarters as part of a total management information and control system. Many of the major units in the plant are expected to be computer monitored or controlled by 1975. The alkylation unit and the heavy oils sections may be under computer control by 1972. Catalytic cracking, vapor recovery, gasoline blending, the desulfurizer, the lube oils extraction unit, and the hydrofinisher are other process units that have major potential for computer control.
Cement plant	Two raw mills, material blending, and kiln control—most of the major steps in cement making at this plant—are expected to be put under automatic control by 1970.
Steel plant	Possible future applications of computer control include the hot strip mill, cold mill reduction, machine shop numerical control, blast furnace burdening, and hot saw cutting of commercial beams.
Steel plant	A computer will be applied to the electric arc furnace, for at least control of the electrical load, and if billet continuous casting is introduced, for coordinating the production of electric furnace steel with casting. A computer also may be applied to basic oxygen furnace operations.

SOURCE: Based on interviews with officials at seven survey plants.

Table B-7. Factors expected to accelerate and retard growth in process computer installations

Factors expected to accelerate use	Factors expected to retard use
Success of present systems	Lack of trained personnel, especially in the areas of process engineering, programing, and computer systems analysis.
Competitive pressure and its emphasis on cost reduction.	
Demand for a better quality product	Absence of full management support, especially when savings due to computer control are difficult to quantify.
Trend toward larger production facilities.	
Larger proportion of plant cost being spent for control instrumentation	Difficulty in justifying computer control in plants or processes with low volume production.
Declining computer costs and continuing development of low cost, reliable computers.	Unsuccessful attempts to control a unit.
Development of computer time-sharing ability which allows one computer to control a number of processes	Computer equipment that does not perform to specifications.
Development of universal programs and process models	Difficulties in developing the mathematical models and programing for complex processes.
Development of direct digital control.	
Increasing complexity of processes which require more sophisticated control systems.	

SOURCE: Based on interviews with officials at survey plants.

APPENDIX C. SELECTED ANNOTATED BIBLIOGRAPHY

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