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A PRELIMINARY ANALYSIS OF THE ECONOMIC IMPACTS OF PROGRAMMABLE AUTOMATION UPON DISCRETE MANUFACTURING INDUSTRIES

UNIVERSITY OF SOUTHERN CALIFORNIA

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Nake M. Kamrany

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INFORMATION SCIENCES INSTITUTE
UNIVERSITY OF SOUTHERN CALIFORNIA
ISI
4676 Admiralty Way/Marina del Rey/California 90291
(213) 822-1511

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13 ABSTRACT

The potential savings of computer-based manufacturing systems are hypothesized. It is our conjectured contention that the development of computer-based automation will yield better benefits than those produced by usual technological progress. However, this approach examines cost savings rather than contribution to growth. The savings impact upon DOD procurement and the production costs of the discrete manufacturing sector is hypothesized by assuming the existence of an automated factory, although such a reality is perhaps several decades away. Many assumptions are made about costs, its components and relationships. A case study, literature references, opinions of consultants, and other case studies and judgmental costs provide the basis for the hypothesis.

Also, the societal impacts of computer-based manufacturing automation are conjectured upon the environment, employment, general price level, urban/rural mix, and international trade. A number of definitions and distinctions are made with respect to automation, productivity, technology, and related points.

* *

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ABSTRACT

In this report the potential savings of computer-based manufacturing systems are hypothesized. It is contended that computer-based manufacturing automation is an extension of the continuing stream of technological progress that the U. S. has been experiencing. Technological progress has significantly contributed to the growth of the GNP with a high rate of return on investment. It is our contention that the development of computer-based automation will yield better than the average benefits derived from technological progress. However, the approach examines cost savings rather than contribution to growth. The savings impact upon DOD procurement and production cost of the discrete manufacturing sector are hypothesized by assuming the existence of an automated factory; although such a reality is perhaps several decades away. Many assumptions are made about costs, its components and relationships. A hypothetical case study, literature references, opinions of the consultants, and other case studies and judgmental costs provide the basis for the hypothesis.

Also, the societal impacts of computer-based manufacturing programmable automation are conjectured upon the environment, employment, general price level, urban-rural mix, and international trade. A number of definitions and distinctions are made with respect to automation, productivity, technology, and related points. Also, some of the major characteristics of the manufacturing industry are identified.

This study was sponsored by the Advanced Research Projects Agency (ARPA) under Contract DAHC 15-72-C-0308. The focus of the work is on the potential economic impact of automation on the DOD procurement. The study also examines the attendant impact on the civilian sector as a by-product.

ACKNOWLEDGMENTS

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I. INTRODUCTION

This is an exploratory statement of the economic impact that the introduction of computer-directed manufacturing systems could precipitate upon the relative costs and other production and nonproduction parameters of engineered manufactured products. An attempt is made to draw certain preliminary estimates of the orders of magnitude, rather than making precise and quantifiable assertions, of economic impact. Many assumptions are made with respect to the feasibility of technical developments and the existence of economic relationships that would be required to satisfy the conditions for bringing about the kind of impacts that are hypothesized. The set of assumptions and relationships are made explicit throughout this document. These assumptions and relationships may be considered reasonable to the extent that most of them are based upon preliminary analysis, estimates made by knowledgeable consultants or referenced in the open literature. Nevertheless, many empirical examinations are required before any assertions can be made.

The primary aim of this study project is to evaluate the possibility and significance of savings to discrete manufacturing industries of the development and application of computer-based manufacturing systems. However, such an exercise, by necessity, raises the issues of relevancy, validity, and synergy with the rest of the economy and the rationality and payoff of the undertaking itself. One does not have to look hard to find numerous examples of the development of sophisticated engineering methods or products whose costs have proven prohibitive or whose economic payoff could not stand serious cost/benefit analysis relative to alternative uses of resources. For instance, in 1971, the SST was voted down by the U.S. Congress after millions of dollars of study and development effort, partly due to the failure of its proponents to provide economic justification for the project.

A. THE CHARACTERISTICS OF PROGRAMMABLE AUTOMATION

The concept of programmable automation needs distinction from the conventional notion of automation. Automation refers to a system of operations with no human factor input. Varying degrees of automation imply corresponding combinations of human and nonhuman factor inputs. Thus, automation is inversely measured by the amount of man-hours embodied in the production of an output. The conventional concept of automation refers to the replacement of labor input in the process of production by a special machine that is designed for a single-function performance that is generally continuous and repetitive; and, if the market demand justifies, the machine could be operated at full capacity. The resulting product is characterized by mass production. Programmable automation is a relatively new concept. Its application is aimed at job shop environments and its characteristics are linked with the advent of computers and associated components (sensors, and software with a feedback mechanism and flexibility). It refers to computer-controlled machines that perform diverse manufacturing operations: designing, prototyping, production engineering, tooling, part forming, assembly, inspection, quality control, material transfer and storage, inventory control, etc. Some or all aspects of the above production steps are already automated, either by computer or noncomputer automation methods. A survey of the current state of the art in computer-based manufacturing systems is contained in a previous ISI report.* The distinguishing technical attributes of programmable automation are assumed below in terms of their economic characteristics.

1. Flexibility

The computer-controlled machine is assumed to bring a new flexibility to automation in that the same machine is able to perform optimally at the

*R. H. Anderson, Programmable Automation: The Future of Computers in Manufacturing, Information Sciences Institute, University of Southern California, ISI/RR-73-2, March 1973. Also see Anderson, R.H., and Kamrany, N.M., Advanced Computer Based Manufacturing Systems for Defense Needs, USC/Information Sciences Institute, ISI/RR-73-10, September, 1973.

same or different configurations, on homogeneous or heterogeneous products, irrespective of the volume of production of any particular product in any given time or production run. It follows that these machines can perform with the same degree of efficiency irrespective of the volume of the job shop or batch production or a single product.

2. Optimal Throughput Time

These machines are expected to have the capability of utilizing different factor inputs and/or readily operating upon different factor outputs with minimal delay time and program reconfiguration. It follows that these machines will have a minimum of downtime.

3. Multipurpose Operations

Since the operation will be programmable, one machine will be able to perform a variety of manufacturing steps instead of a single-purpose operation. This factor alone will contribute significantly to maximum utilization of plant and efficient utilization of individual machines (assuming sufficient market demand exists to keep operations at full capacity).

4. High Reliability

The nature of production is such that it requires minimum human intervention in the routine processes and, therefore, is not constrained by human variability or reaction time. All production components are programmable, and are highly integrated with the firm's computer-aided designing and engineering facilities, accounting, production control, and management information systems.

5. Optimal Scheduling

These production process flexibilities will be combined with optimal scheduling (queuing of) and allocation of resources, including an optimal inventory level of both inputs and outputs.

The above distinguishing characteristics of programmable automation present new insights and possibilities into the conventional and accepted norms of the theory of production and production function of the job shop firms. These firms operate at less than mass production rates, producing either intermediate or finished discrete manufactured products. The economic characteristics of the discrete manufacturing industries are discussed below.

B. THE ECONOMIC CHARACTERISTICS OF THE DISCRETE ENGINEERING MANUFACTURING SECTOR

The manufacturing sector as a whole absorbs more than 25 percent of the total work force in the United States, and is the most significant single item in the national income accounts, contributing 30.2 percent of value added in 1970. This is about nine times the contribution of agriculture or construction, and three times finance and insurance. (See table 1).

The structure of most mature economies, including the United States, is expected to shift in favor of the service sector. However, the micro-contents of such a shift do not provide clear-cut answers on the outcome or relative shares of the various industries, industry groups, and/or SIC classifications.*

For instance, it has become apparent that certain of the service sectors (e.g., transportation, medical care, housing, utilities), while growing in relative terms, have become more capital intensive; that is, they contain higher degrees of technology as measured in terms of direct labor input per unit of output. The 1962 capital/output ratios of U.S. industries show that farming, public utilities, communications, railroads, and petroleum and coal have the highest ratios, while machinery, motor vehicles, and other durables have very

*Standard Industrial Classification (SIC) codes are used by the Department of Commerce to designate categories and subcategories of industrial goods. For example, SIC code 37 refers to Transportation Equipment; SIC code 3729 refers to Aircraft Equipment. The codes are defined to a seven-digit precision.

Table 1

GNP BY INDUSTRIAL ORIGIN*

	1970	% Contribution in 1970
Agriculture	25.3	3.5
Construction	23.0	3.2
Manufacture	217.1	30.2
Transport	77.2	10.7
Wholesale	127.1	17.7
Finance & Insurance	97.0	13.5
Services	68.6	9.5
Government	69.9	9.7
Others	14.9	2.0
Total GNP	720.0	100.0

*In billions of 1958 dollars.

Source:
Economic Report of the President, January 1972, Table B-9.

low capital/output ratios.* Therefore, changes in the structure of the economy do not provide a useful breakdown for estimating or inferring the future relative positions and trends of the various sectors of the economy. Such a breakdown would have to be treated with a great deal of caution. Nevertheless, one thing is quite clear: nearly all sectors of the economy in the future will have more technology embodied in them. (see Table 2).

Within the manufacturing industry a similar variance is observed with respect to the rate of technological change and automation in the production of durable as well as nondurable goods. A majority of the nondurable manufactured goods are produced by process manufacturing industries, such as chemicals, petroleum, paper, and others which are highly automated. This research project deals with the discrete engineered manufactured products that are the most affectable by computer-based manufacturing systems. (see Table 3).

The main features of the discrete manufacturing engineering products (DMP) are:

Batch Production Methods

1. A predominance of batch manufacturing methods (instead of a single-line flow-through production process) in which the machines are set to produce a few hundred intermediate or finished products per production run. Estimates of the amount of physical output of U.S. industrial engineering batch production methods ranges between 70 to 85 percent.**

*Bert C. Hickman, Investment Demand and U.S. Economic Growth, (Washington, D.C.: The Brookings Institution), 1965.

**Phillip O. Geier, "A Machine Tool Industry Viewpoint on Overcoming Technological Blockages to Manufacturing Productivity," SME Technical paper, 1972. Also, see Doyle, L.E., Keyser, C.A., Leach, J.L., Schroder, G.F. and Singer, M.B., Manufacturing Processes and Materials for Engineers. Inglewood Cliffs, N.J. Prentice-Hall, 1969.

Table 2

CAPITAL-OUTPUT RATIOS, U.S. INDUSTRIES, 1962

Industry or Sector	1962
Total manufacturing	.66
Primary metals	1.38
Machinery	.34
Motor vehicles	.48
Nonautomotive transportation equipment	.42
Stone, clay, and glass	.79
Other durables	.39
Food and beverages	.42
Textiles	.81
Paper	.83
Chemicals	.68
Petroleum and coal	2.28
Rubber	.52
Other nondurables	.22
Railroads	4.63
Nonrail transportation	.70
Public utilities	3.54
Communications	1.73
Commercial and other	.65
Farming	2.57
All industries covered by the study	1.01

Source:
Bert G. Hickman, *Investment Demand & U.S. Economic Growth* (Washington, D.C.: The Brookings Institution, 1965), p. 152.

Table 3

DURABLE AND NONDURABLE GOODS INDUSTRIES

CODE	Industry Group and Industry	1970 All Employees Number (1,000)	1970 Production Workers Number (1,000)	1970 Value Added by Manufacture ($ Million)
		A	C	F
	All manufacturing establishments, including administrative and auxiliary units, total	19,241.4	13,553.0	298,276.2
	Operating manufacturing establishments	18,312.0	13,553.0	298,276.2
	Nondurable goods	7,567.3	5,683.4	128,686.2
201-2	Meat and dairy products	521.7	349.7	8,116.4
203-6,209	Food crop products	803.2	584.7	16,284.9
207-8,21	Beverages, candy, & tobacco	385.2	248.9	9,982.3
22,31	Textile and leather products	1,217.5	1,073.1	12,056.5
23	Apparel and other textile products	1,330.2	1,169.3	11,601.2
26	Paper and allied products	656.6	518.5	11,530.4
27	Printing and publishing	1,081.1	654.7	17,265.3
281-2	Industrial chemicals	439.6	293.7	13,251.1
283-9	Chemical products	438.4	260.7	14,694.7
29	Petroleum and coal products	145.9	101.1	5,443.9
30	Rubber and plastics products,n.e.c.	547.6	429.0	8,459.5
	Durable goods	10,744.7	7,869.6	169,590.0
24	Lumber and wood products	545.2	478.8	5,859.3
23,39	Furniture & Miscellaneous industries	864.6	697.1	10,313.6
32	Stone, clay, and glass products	595.3	474.0	9,866.5
331-2,339	Iron and steel industries	898.4	729.2	14,653.7
333-6	Nonferrous metal industries	361.2	282.9	6,716.0
342-4	Construction metal proudcts	611.7	454.0	9,247.0
341,345-9	General metal products	724.9	574.9	11,461.4
354-6	Manufacturing machinery	792.3	550.8	12,603.7
351-3,357-9	Other nonelectrical machinery	1,097.6	755.1	19,143.1
365-7	Communication products and parts	1,008.9	614.2	14,359.2
361-4,369	General electrical products	831.5	623.1	13,437.3
371	Motor vehicles and equipment	720.2	580.1	14,523.8
372-9,1925	Aerospace and transit equipment	1,109.3	670.6	17,238.4
38,19 exc. 1925	Instruments and selected ordinance products	583.6	384.8	10,162.0
	Administrative and auxiliary[1]	929.4	(X)	(X)

Source:

Annual Survey of Manufacturing: 1970, Department of Commerce, Bureau of the Census, February 1972.

Underutilization of Machines

2. Such production runs create a great deal of underutilization of machine tools, since most of the machinery is special purpose or single function. Machine tools are estimated to be utilized one-third of the time and parts-in-process utilized only 5 to 15 percent of the time. Among the factors contributing to this underutilization are operations scheduling, single purpose rather than multipurpose machines, and marketing conditions. This is indeed expensive since machine costs have been increasing at the same high rate as labor costs.

Machine Obsolescence

3. Capital goods used by U.S. manufacturing suffers from old age and obsolescence. One estimate indicates that 80 percent of the machine tools in the U.S. are at least 30 years old; another states that 64 percent are 10 years old or older. F. J. Trecker calculates that 2,200,000 standard machines have been installed over 40 or more years.* It is estimated that the replacement cost of the existing old and obsolete equipment will amount to around $100 billion. The above conditions have culminated in production processess that are underutilized and inefficient, which require long production-cycle times and long working of production time.

Slow Replacement Rate

4. In spite of the old age of the machine tools, the replacement rate of old tools with new ones is a function of many factors, including:

*Francis J. Trecker, "Industry Advisory Council Subcommittee on Industrial Mobilization," (New York), January 11, 1971. Also, see U.S. Department of Commerce, U.S. Industrial Outlook, 1972.

- tool age and wear
- replacement cost
- improvement in tool design and construction
- expected product demand and its duration
- financial condition of the firm
- policies of individual
- availability of retained earnings of risk capital
- cost of new machines in relation to labor costs
- availability of skilled workers/programmers to effectively operate the new machines
- tax incentives, including depreciation.

The following additional factors relate specifically to numerical control (NC), direct numerical control (DNC), and robotics:

- user's mechanical sophistication and ability to fully utilize these new machines
- product design that lends itself to automatic operations, including assembly.

H. D. Wagoner made the following observation, concerning machine tool replacement during 1900-1950, which probably still holds:

> Machine tools replacement was often almost indefinitely deferrable and was, therefore, an undependable element in machine tools demand.*

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*Harien D. Wagoner, The U.S. Machine Tool Industry from 1900 to 1950 (Cambridge, Massachusetts: The M.I.T. Press), 1968, p. 338.

The slow rate at which the metal cutting industry is adopting NC tools (20,000 or 1 percent of the total) attests to the validity of the above statement. If the application of NC tools relative to the total output of the firm is examined, this figure probably does not change appreciably. However, it is conjectured that the NC tools are adopted at an appreciably higher rate than the conventional ones.

<u>High Labor Content</u>

5. More important, however, is that 68 percent of U.S. manufacturing costs are for labor compensation. From 1965-1969, increases in labor costs (compensation minus productivity) in the manufacturing sectors were 16 percent or 3.7 percent annually.

<u>R&D Costs</u>

6. The problems of capital equipment obsolescence and a chronic cash flow faced by these industry firms preclude renovation and the R&D expenditures necessary for modernization and productivity improvement. One study shows that R&D per project depends upon the firm's cost of generating new information, its cost of future output, and its marketing ability. R&D costs per unit of sales are lower for large firms.*

<u>High Indirect Costs</u>

7. Many firms' indirect costs (managerial, professional, and technical personnel), their components, and relation to direct costs, are not well understood. They appear to be increasing at a faster rate than direct costs. In some plants the cost of knowledge

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*Lawrence Goldberg, "The Demand for Industrial R&D," Brown University Ph.D. Dissertation, 1972 (unpublished).

workers is two-thirds that for the total employees, and a higher percentage of the dollar costs since knowledge workers cost more than direct workers.* Ways of increasing the productivity of indirect workers could result in an appreciable reduction in unit costs. For instance, the wages of nonproduction workers in ordnance constituted 50 percent of the total payroll; 34 percent of total employment in the durable manufacturing industries in 1970 was in managerial and other nonproduction occupations.**

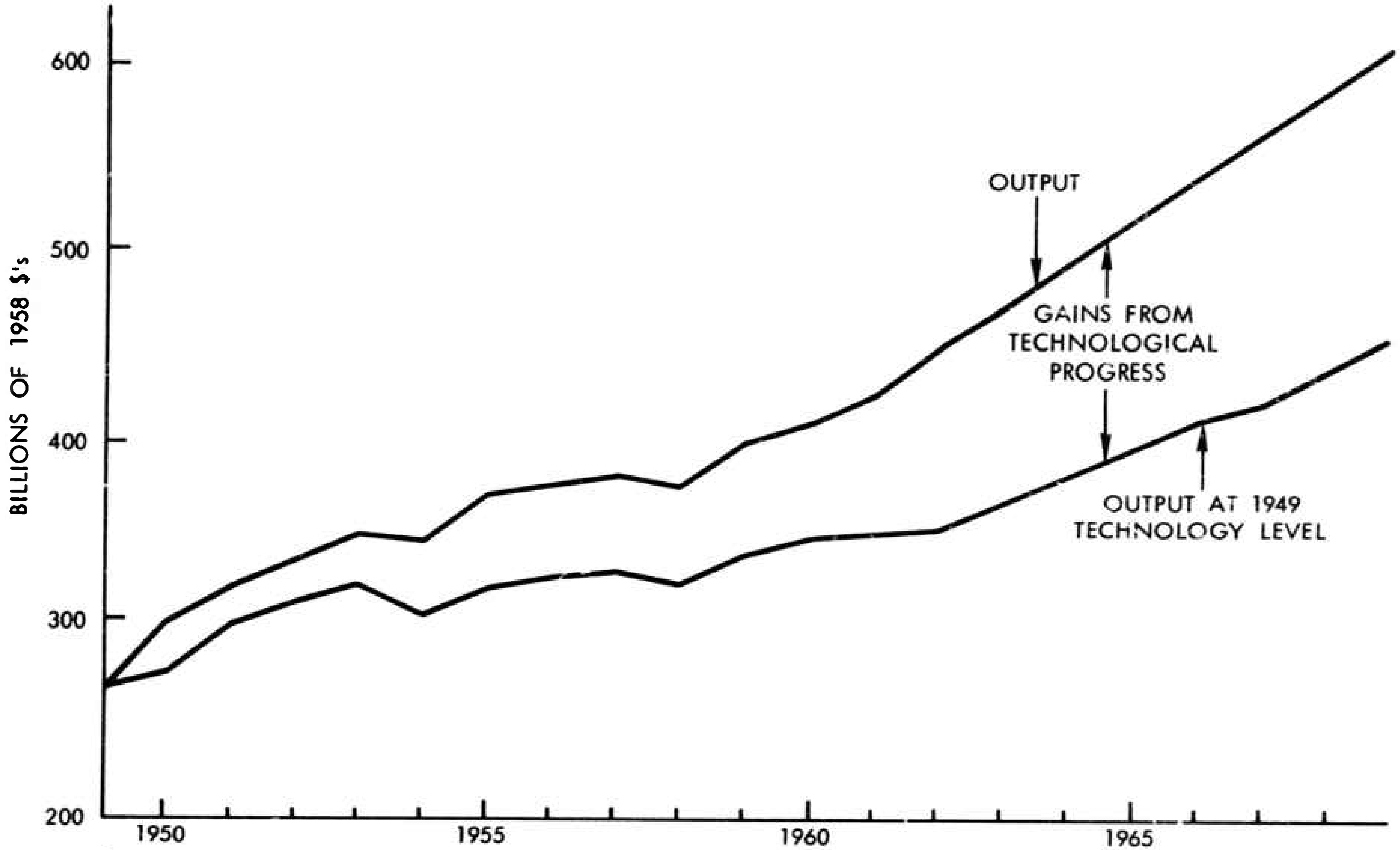
C. HOW PROGRAMMABLE AUTOMATION CAN IMPACT THE PRODUCTION OF DISCRETE MANUFACTURING PRODUCTS: AN ILLUSTRATIVE MODEL

Computer-based manufacturing is conceived as an addition to the continuing stream of the nation's technological progress in the engineering manufacturing industries. Technological progress refers to the application of previously unused or new methods of production. Technological progress has been studied in its macro and micro aspects. At the national level, one study reports that U.S. technological progress from 1949 to 1968 accounted for 40 percent of the real income in private (nonfarm) output. This amounts to about 20 percent more output than might otherwise have been achieved with the same quality of labor and capital. Therefore, a cumulative output was achieved of $8.2 trillion instead of $6.9 trillion, for a net gain of $1.3 trillion as a result of technology. The net gain represents a 1.7 percent per year growth in the technology factor during the 1949-1968 period.*** By 1968, the compounding growth of technology had amounted to 37 percent of the total output, according

*Thomas M. Liptak, "Manufacturing Software Development and Application," SME Technical Paper, 1972.

**United States Department of Labor, Current Population Survey.

***Illustrated in Fig. 1.



Source:
"Economic Impact of Stimulated Technological Activity", Midwest Research Institute (Contract NASW-2030), Summary Vol., November 1971, 1.9.

Figure 1. Output and gains resulting from technological progress (1949-1968).

to a recent study.* The study concludes that on the average, each dollar spent on R&D returns slightly over seven dollars in technologically-induced economic gains over an 18 year period following the expenditure. The discounted rate of return for such an investment amounts to 33 percent per annum. From this it follows that R&D expenditures in general appear to be a very good national investment.

On an industry level, one study of the impact of technology in the United States petroleum industry shows that from 1939 to 1968 real prices increased by 64 percent, instead of 233 percent in the absence of new technology. The contribution of new technology and cheaper inputs was credited for a savings of 169 percent points.**

On the microlevel, many examples of dramatic productivity improvements have been reported. A few examples are cited below:

- A major manufacturer of oil and gas equipment cut work-in-process time by 40 percent, reduced in-process inventory 22 percent, and saved at least 1600 man-hours each month. These are some of the advantages that resulted from their new on-line job reporting system.

- Design engineers at an aircraft company reported they were up to twenty times more effective in solving design problems by using graphic display units.***

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*"Economic Impact of Simulated Technological Activity," Summary Volume, Midwest Research Institute, 1971.

**Norman B. Norgaard, "Output, Input, and Productivity Change in U.S. Petroleum Development: 1939-1968," University of Chicago Ph.D. Dissertation, 1971.

***Thomas M. Liptak, op. cit.

In the preliminary phase of the impact study of programmable automation at The Rand Corporation, the following potential savings were identified:*

- Cost reduction for product innovation, since 45 to 75 percent of the costs associated with a typical successful product innovation are attributed to tooling and manufacturing start-up expenses.

- Climate for innovation could become less capital restrictive. Reduced capital investment requirements, especially for limited production could ossible.

- Productivity increases between 150 to 400 percent are routinely reported by firms substituting NC tools for conventional ones in the metalcutting process.

- Reduction in capital costs is more speculative, depending upon the range of renovation (e.g., from building a new plant to piecemeal modernization of an existing one). Our simulation estimate of the capital outlay for an automated facility, producing small electromechanical multiples at a rate of 600 units per month, amounted to around $11 million. This compared favorably with an estimate, by representatives of the conventional facility, of a replacement cost of $80 million.

- A great deal of cost reduction is also attributable to improvements in engineering changes, inventory reduction, scrap and rework costs, or tool-up costs.

- Estimates of manufacturing cost reductions range between one-fourth to one-half that of the conventional factory cost, depending upon the share of costs attributable to outside purchases, and the degree to which these purchases are produced by programmable automation rather than conventional methods.

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*See preliminary report, Computer-based Automation of Discrete Product Manufacture: A Preliminary Discussion of Feasibility and Impact, The Rand Corporation, R-1073-ARPA, Santa Monica, California, June 1972.

The above statements require a great deal of macro- and microanalysis. The verification of such estimates depends upon the availability of solid data. Such data cannot be obtained unless programmable machines and factories are developed. To this extent, estimates are speculative and subject to risk and uncertainty. However, it is possible to develop a number of typical cost distributions for a number of major product mixes and simulate them as a factory model for a better evaluation of the impact of programmable automation as compared to conventional methods. Assuming that the market pull or international competitiveness will induce the development of programmable automation, our a priori view of the post-innovation period tends toward the following improvements:

- Production could be made flexible such that a wide range of goods could be produced, at varying rates of production runs per unit of time, thus substantially reducing unit-cost variance due to the number of products produced;

- Small firms could improve their efficieny by drawing upon production service bureaus on demand, and thus minimize excess capacity and investment in heavy capital equipment;

- Machinery and component utilization rates could improve significantly;

- Machine obsolescence will not cause heavy financial burdens, since the cost will be spread among many users (similar to participating in time sharing or service bureaus);

- Production cycle and time will be shortened substantially;

- Relative share of indirect labor as a percentage of unit cost will diminish significantly.

The qualitative and quantitative impacts of programmable automation depend upon an accurate identification of major problems and priority ordering of them with respect to their relative costs, including direct and indirect costs. The logic of such an approach is briefly explained below.

Let x(i,j) stand for a combination of ith industry special characteristics, (DMP) as defined previously, and jth programmable automation (PA) attributes. For example, x(11) could be the reduction in idle time (industry characteristic 1) in a specific multipurpose machine (PA attribute 1). Such reductions in idle time can be converted into a certain percentage gain to the factory system. These gains can be measured by some efficiency measure, such as dollar savings or increase in productivity or shipments, etc. Thus, for each x(i,j) we can associate a savings factor depicting the relative gain over the conventional method. The derivation of these expected gains is possible by a simulation of the entire PA system. The approach is illustrated in the following matrix.

Table 4

MATCHING INDUSTRY CHARACTERISTICS WITH AUTOMATION ATTRIBUTES

Industry Characteristics (Problems) (DMP) i↓	PA ATTRIBUTES j→				
	1	2	3	4	5
1	$x_{1,1}$		$x_{1,3}$		
2		2,2			
3				$x_{3,4}$	
4			$x_{4,3}$		
5	$x_{5,1}$				$x_{5,5}$

In Table 1, each entry in the matrix depicts an impact upon one or more of the production steps in the form of varying degrees of savings that could be reduced to a common denominator, i.e., the dollar. Also, the element in the matrix reveals the degree of savings corresponding to varying degrees of automation. Moreover, such savings or cost reductions could be identified in the production process by once again developing and estimating the necessary matrix between the values of x(i,j) and the production steps as illustrated with hypothetical data in Table 5.

The last row shows the percentage of cost reduction at various production steps, adding to a numeraire of 100. The last column shows the percentage gain or improvement in the bottleneck characteristics after adopting PA. Assuming independency of these two classifications,* we can estimate the impacts on each production step coming from certain x(i,j). For example, if the cost reduction in assembly operation is 30 percent and the total gain from x(1,2) is 15 percent, then 4.5 percent is the cost reduction in assembly due to the improvements of the DMP from PA of the type x(1,2).

*Setting a general model with interaction effects is much more realistic but far more difficult.

Table 5

THE IMPACT OF PA UPON PRODUCTION STEPS

PA-DMP Combination	Design	Prototype	Engineering	Shaping	Assembly	Inspection	Packing	Quality-Quantity Gain in %
$x_{1,1}$	1	1	2	1	3	1.5	0.5	10
$x_{1,2}$	1.5	1.5	3	1.5	4.5	2.25	0.75	15
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
$x_{5,5}$	1.6	1.6	3.2	1.6	4.8	2.4	0.8	16
% of Cost Reduction	10.0	10.0	20.0	10.0	30.0	30.0	15.0	100.0

II. IMPACT UPON DOD PROCUREMENT

In a decade of rapidly increasing federal expenditures, United States defense outlays (defense, space, and foreign affairs) declined during FY 1963-FY 1973, from 53 percent to 34 percent of the total government expenditure, although in absolute terms they increased from $34 billion to $58.9 billion. Table 6 shows the changing composition of federal expenditures over the last decade. The defense programs reflect the Administration's minimum requirements to meet the U.S. domestic and global objectives based upon a systematic relationship between military forces and national security requirements.

Nevertheless, the defense budget continues to be a subject of debate and controversy. Weapon systems acquisitions output and prices are the focus of the controversy since the existing Congressional procedures for reviewing the defense budget are designed to examine them closely. Prices and outputs are easy to assess systematically and therefore tend to become the targets of controversy.

The $4.3 billion cut from the President's 1973 defense budget (now at $74.3 billion) are exemplary: most of the cuts in each of the three services were in the areas of new weapons, research and development, operations and maintenance and some reduction in personnel strengths.

Aside from the declining cost of Vietnam, two factors have dominated changes in the defense budget: first, the rising cost of manpower, and secondly, the rising cost of weapon systems.

In FY 1973 military and civilian salary and other personnel costs will take up 56 percent of the total defense budget. This figure was 43 percent in 1964. However, there is a relationship between the equipment needs and the manpower requirement. Any measure that can affect the nature and cost of equipment could also have significant impact upon the manpower needs and thus, some improved balance between the two could be achieved.

Table 6

THE CHANGING COMPOSITION OF FEDERAL EXPENDITURES
FISCAL YEARS 1963, 1970 and 1973

Category of Expenditure	Billions of Dollars			Percent of Total		
	1963	1970	1973	1963	1970	1973
Defense, space, foreign affairs	58.9	87.7	88.0	53	44	34
Older income maintenance programs	28.4	49.8	74.9	25	25	29
Major "Great Society" programs	1.7	21.2	35.7	2	11	14
Commerce, transportation, natural resources	7.6	11.6	16.5	7	6	6
President Nixon's new initiatives	...	...	6.4	..	..	2
Interest (net)	7.7	14.4	15.5	7	7	6
Other programs	7.2	13.6	19.3	6	7	8
Total	115.5	198.3	256.3	100	100	100
Expenditures as a percent of full employment gross national product						
Total	18.4	20.3	20.5	...	...	...
Total, less defense, space foreign affairs	8.7	11.3	13.4	...	...	...

Source:
The Budget of the United States Government, for fiscal years 1973, 1972, and 1965, see C. L. Schutze, et al., *Setting National Priorities*, The 1973 budget, Washington, D.C.: The Brookings Institution, 1972.

Presently, about 15 percent of military personnel have a combat job while the remaining 85 percent provide a variety of supportive services, including manpower requirements for maintaining more advanced systems. It is conceivable that computer-based manufacturing systems could contribute both to lowering of the procurement costs as well as improving the efficiency of the noncombat manpower requirements, thereby improving the existing ratio of combat to support manpower requirements, and thus meeting the same requirements at lower costs.

In addition to the financial and budgetary considerations, it is our view that computer-based manufacturing could contribute to a multitude of U.S. defense and nondefense policy postures as they relate to considerations such as rapid conversion from civilian to defense production and vice versa, effectively responding to the length and intensity of a conflict, the extent to which peacetime forces are maintained, mobilization lead time, manpower factors, and the concepts used in designing new weapon systems, manufacturing production efficiency, and international competitiveness.

In this study, however, one of the main aims is to illustrate the impact of programmable automation upon reducing the cost of weapons and other military procurements. We believe that present decisions related to the rate and degree of automation and improved technologies for application in the production and acquisition of military procurement will affect the cost at which military forces will be modernized. The development of programmable automation could lead to substantial savings after three to five years and could affect operating costs over the next several decades.

The above statements are predicated upon the characteristics of defense weapon procurements (DWP) and the attributes of programmable automation (PA). The combination of these two appear to have a very high synergistic value and, in turn, significant savings impact. The mechanical characteristics of defense weapon procurements appear to have a much greater synergistic value than the discrete manufacturing products (DMP) of which DWP is a part. If we designate

$Y(i,j)$ as the synergistic value of DWP and PA, then ΣY_{ij} is greater than ΣX_{ij}. The underlying reasons may be sought in the characteristics of DWPs as discussed below. These characteristics are as follows:

1. More than 70 percent of defense procurement may be considered as manufactured by batch production in terms of quantity as illustrated below:

Quantity Purchased Per Year	1971 DOD Procurement $ Billions
0-10	3.7
11-100	3.4
101-1,000	1.9
1,001-10,000	.1

The above relationship is illustrated in Figure 2. (Source: Department of Defense, 1972.)

2. The cost components of defense procurement items (discrete engineered products) contain a very high labor (direct and indirect) content as shown in Table 7 below.

A preliminary exercise of analyzing the potential magnitude of savings to DOD was carried out under the assumption that fully programmable automated factories of the following characteristics existed for all requisite production processes (from armored tank manufacture to electronic avionics system production). Needless to say, this hypothetical situation would not exist until decades after feasibility was demonstrated in R&D programs. The characteristics assumed were:

- programmable automated assembly machines
- programmable automated testing machines
- programmable automated fixturing

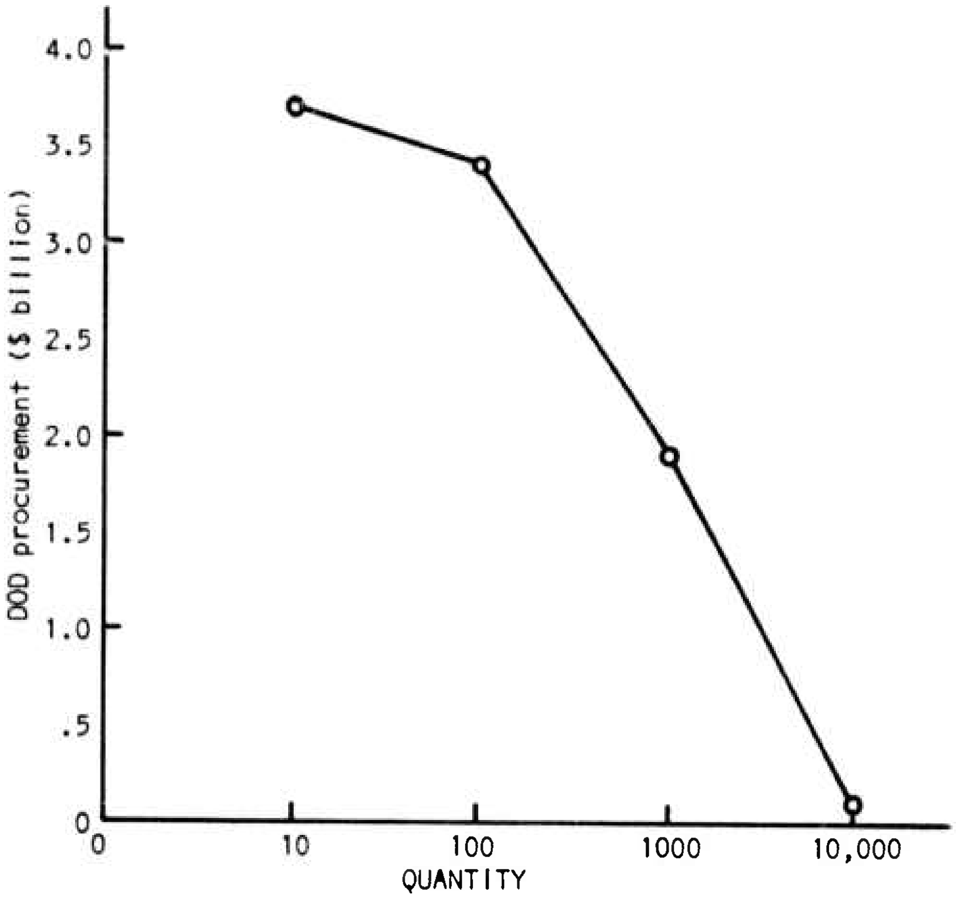

Fig. 2 - Relationship between procurement rate and procurement expenditures.

Table 7

RELATIVE COST DISTRIBUTION OF A RECENT
HIGH PERFORMANCE MILITARY AIRCRAFT

	Direct Labor	Overhead	Material	Other Direct Charges	Total
Engineering	11%	10%	-	1%	22%
Tooling	3	4	-	-	7
Quality Control	3	5	-	-	8
Manufacturing	23	31	9%	-	63
Totals	40%	50%	9%	1%	100%

Human related costs (direct labor and overhead) constitute 75% of the total in-plant costs while manufacturing and engineering functions constitute 85% of the total in-plant costs.

- programmable automated conveying systems
- high level production programming languages and software systems
- technology for integration of the entire factory system.

In Table 8 the major procurement items (such as aircraft, missiles, ships, and ordinance) and corresponding dollar expenditures are listed (columns 0 and 1). In column 2 the relative shares of discrete manufactured products in each category of procurement are estimated. Column 3 provides the dollar value of discrete manufactured products purchased in 1971. In columns 4 and 5 the relative and absolute shares of these discrete products that are amenable to automation are estimated. Column 6 provides the estimated percent savings due to the application of programmable automation and the absolute figures of savings are calculated in column 7 which amounts to $2.28 billion of the 1971 defense budget.

The real significance of the savings is illustrated in Table 9 and Figure 3. As shown, procurement costs of the conventional vs. automated systems shows larger amounts of savings at production rates of less than 100 than at other procurement rates.

In Table 10 the absolute and relative impact of programmable automation upon the 1971 DOD budget and its various components including discretionary, non-discretionary procurement and procurement of discrete products is summarized. The amount of savings is $2.28 billion or 17 percent of the total DOD manufacturing purchases. These figures are indeed significant by themselves relative to DOD budget. However, thay gain more significance when the spillover effect of PA is also measured upon the rest of the economy.

Table 8

DOD PROCUREMENT OF SPECIFIC ITEMS
AND THE IMPACT OF PROGRAMMABLE AUTOMATION
FY 1971 - Millions of Dollars

Item	(1) Actual DOD Procurement	(2) % Discrete Man.	(3) Value of Discrete Man. Purchased	(4) Amenable to Prog.Auto.	(5) Value of Discrete Man. Amenable to Prog.Auto.	(6) % Saving Due to Appl. of Prog.Auto.	(7) Saving Due to Application of Prog.Auto.
Aircraft	3,249	90%	2,800	50%	1,440	50	720
Modification of Aircraft	834	90	750	60	450	30	135
Spares and Repair Parts	942	90	840	80	670	50	340
Support Equipment & Facilities	1,055	20	210	90	190	50	95
Ballistic Missiles	1,057	90	945	50	470	50	235
Other Missiles	443	90	398	100	398	50	199
Modification of Missiles	128	90	115	70	80	50	40
Spares and Repair Parts	69	90	62	80	49	50	24
Support Equipment & Facilities	636	20	127	90	114	50	57
Combat Vehicles	69	90	62	30	18	20	3
Ammunition	774	90	696	10	69	0	0
Fleet Ballistic Missile Ships	360	90	324	10	30	15	5
Other Warships	1,524	90	1,350	10	135	15	20
Amphibious ships	312	90	280	10	28	10	2.8
Auxiliaries and craft	159	90	143	10	14.3	20	3
Ship Support Equipment	540	90	486	80	388	40	155
Communications & Electronics	311	90	279	100	279	30	84
Aviation Support Equipment	278	90	250	80	200	30	8
Ordnance Support	431	90	388	80	310	40	124
Civil Engineering Support Equip.	49	90	44	70	31	20	6
Supply Support Equipment	6	90	5	70	3	20	1
Personnel and Command Support	59	90	53	70	37	60	22
TOTAL	13,285		10,687		5,373		2,278.8

Table 9

PROJECTED RELATIVE AND ABSOLUTE SAVINGS FROM PROGRAMMABLE AUTOMATION AS A FUNCTION OF NUMBER OF ITEMS PRODUCED PER YEAR

Quantity	Conventional Prod.	Prog. Automation	% Savings	Billion Savings
1-10	9	7.02	22	0.8
11-100	7.5	5.1	32	1.1
101-1,000	4	3.3	17	0.33
1,001-10,000	2	1.9	5	0.05
10,000	1	1.0	-	0.01

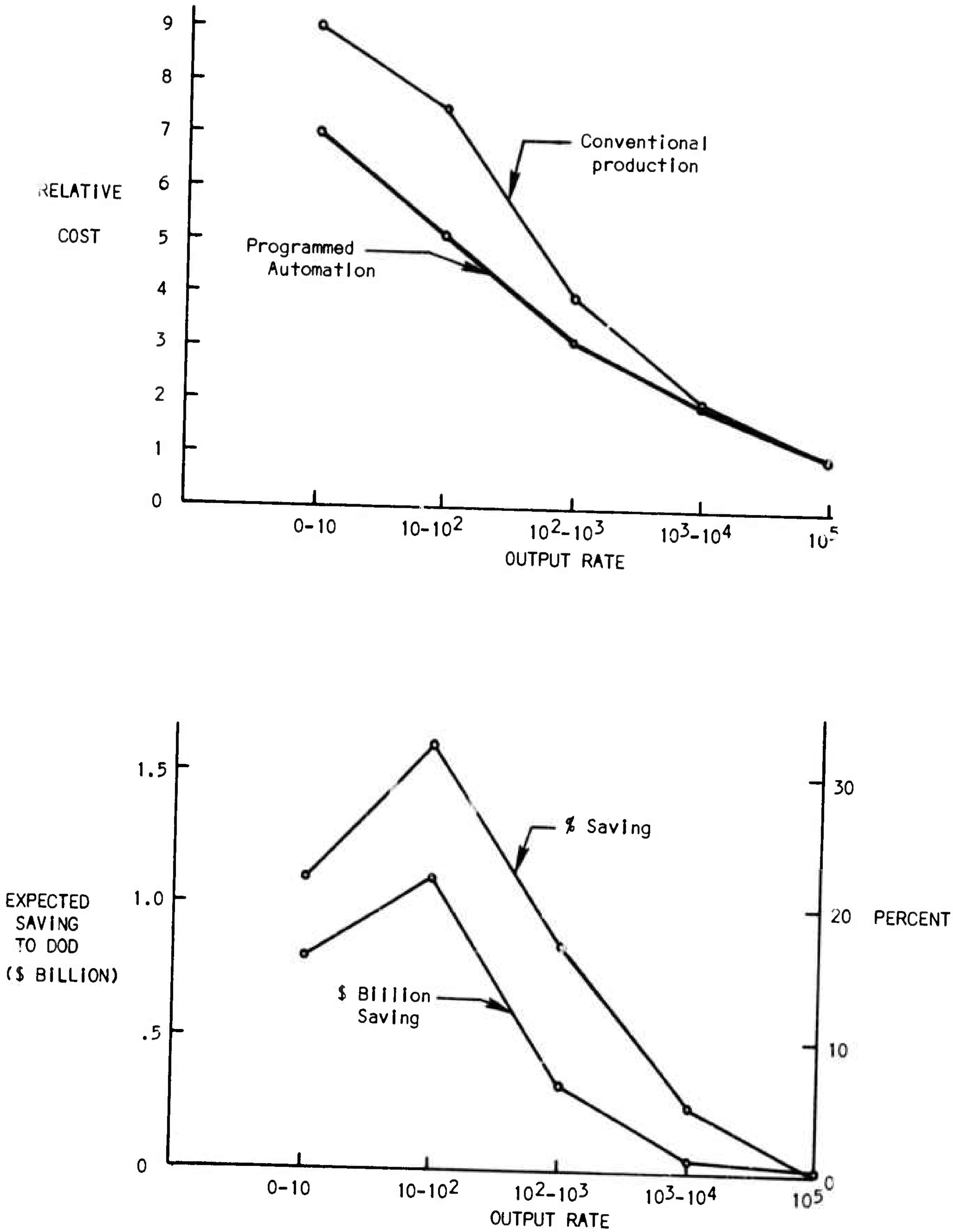

Fig. 3 - Comparative costs and savings from programmable automation

Table 10

THE IMPACT OF PROGRAMMABLE AUTOMATION ON THE DOD BUDGET

	$ Billions[1]	% of DOD Budget	% of DOD Procurement	% of Total DOD Mfg. Purchases	% of Discrete DOD Mfg. Purchases
DOD Budget	71.3				
Non-Discretionary:					
Military Personnel[2]	26.0	36.48			
Operations & Maintenance	20.4	28.61			
Total non-discretionary	46.4	65.09			
Discretionary:					
Procurement	15.7	22.2			
Research, development, test & evaluation	7.1	9.96			
Misc.[3]	2.1	2.95			
Total Discretionary	24.9	34.92			
DOD Procurement - Total Mfg.	13.3	18.65	84.71		
Discrete Mfg.	10.69	14.99	68.09	80.37	
Amenable to Prog. Auto.	5.37	7.53	34.20	40.38	50.23
Savings from Prog. Auto.	2.28	3.20	14.52	17.14	21.33

1. New obligational authority, 1971 actual.
2. Includes retired military personnel.
3. Includes military construction.

Source:

The Budget of the U.S. Government, Fiscal Year 1973, Executive Office of the President: Office of Management and Budget.

III. IMPACT UPON THE CIVILIAN SECTOR

In this section a brief preliminary analysis of the spinoff effect of programmable automation is made upon a number of major national concerns such as productivity in the manufacturing sector, international trade, price stability, employment, industry structure, rural-urban mix and the environment.

A. IMPACT UPON MANUFACTURING INDUSTRIES

DOD's procurements from the manufacturing sector amount to around $20 billion or seven percent of the total value added of this sector ($300 billion). Table 14 provides the results of an exercise to analyze the impact of PA upon the operating cost of the manufacturing industry assuming that fully programmable automated factories existed. (Again, we emphasize that this situation could not be realized for decades.)

As shown in Table 11, the manufacturing sector is divided into 21 two-digit standard industrial classification (SIC) codes (see column 1). The titles of these codes are provided in column 2. The operating cost of these SIC codes in 1969 dollars are recorded in column 3. The percentage of each SIC code that falls into discrete products is recorded in column 4. In column 5 an attempt is made to estimate the proporation of each of the discrete products that are amenable to the application of programmable automation. The percent of the industry affected by automation is derived from the product of columns 4 and 5. The percent savings from PA in the affected portion of the industry is estimated in column 7, and the expected relative and absolute savings to each of the industries are estimated in columns 8 and 9, respectively.

Table 11

IMPACT OF PROGRAMMABLE AUTOMATED SYSTEM ON MANUFACTURING INDUSTRIES

SIC Code	Title	Operating Costs in 1969 $ Billion (c)	% of Discrete Product	% Amenable by PA	% of the Industry Affected by Auto.	Expected % Savings from PA	Expected % Savings to Each Ind.	Expected Savings 1969 $ Billion to each Ind.
1	2	3	4	5	6	7	8	9
19	Ordnance & Accessories	8.28	100	95	95	10	9.5	0.79
20	Food & Kindred Products	76.60	50	80	40	25	10.0	7.66
21	Tobacco Manufacturers	3.23	100	100	100	0	0	0
22	Textile Mill Products	19.52	0	0	0	0	0	0
23	Apparel (fabric)	19.30	100	60	60	10	6.0	1.16
24	Lumber & Wood Products[a]	0.60	100	50	50	15	7.5	0.05
25	Furniture[b]	4.14	100	50	50	15	7.5	0.31
26	Paper	19.43	50	40	20	8	1.6	0.31
27	Printing	17.62	50	80	40	0	0	0
28	Chemicals	31.57	10	0	0	0	0	0
29	Petroleum Refining	21.16	10	0	0	0	0	0
30	Rubber	12.27	50	50	25	20	5.0	0.61
31	Leather	4.30	100	60	60	10	6.0	0.26
32	Stone, Glass	12.52	30	50	15	0	0	0
33	Primary Metal	47.08	20	5	10	30	0.3	0.14
34	Fabricated Metal	31.07	100	50	50	10	5.0	1.55
35	Machinery	42.86	100	50	50	40	20.0	8.57
36	Electrical	37.58	100	70	70	15	10.5	3.94
37	Transport Equipment	67.73	100	10	10	25	2.5	1.69
38	Professional Instruments	7.87	100	10	10	30	3.0	0.24
39	Miscellaneous	7.27	100	20	20	20	4.0	0.29
19-39	Total Manufacturing Ind.	$492.00	64.15%	40.20%	25.79%	17.85%	5.6%[d]	$27.57

(a) The saving applies only to SIC Code 2433

(b) The saving applies only to SIC Codes 2511, 2512, 252

(c) Total operating cost estimated as: Payroll + cost of material + capital expenditure

Savings in cost obtained by applying % savings (to SIC Code) on the operating costs.

(d) % savings to the manufacturing industry $= \frac{\Sigma(\text{\% savings}) \times (\text{operating costs})}{\Sigma\,\text{operating costs}}$

Source for Value Added: Industry Profiles 1958-1969, U.S. Department of Commerce, 1971.

Table 12

IMPACT OF PROGRAMMABLE AUTOMATION UPON MANUFACTURING SECTOR

		In 1969 $ Billion	% of GNP	% of Mfg.Ind.	% of Discrete Mfg.Prod.
	1	2	3	4	5
1	GNP	929.1			
2	Mfg.Industry	305.9[(a)]	32.92		
3	Discrete Mfg.	206.24[(a)]	22.20	67.42	
4	Programmable Discrete Mfg.	85.94[(a)]	7.25	28.09	41.67
5	Savings from Prog.Automation	27.57	2.97	9.20	13.64

Sources:

(1) *Economic Report of the President, 1972:* data on GNP.

(2) *Industry Profile 1958-1969:* data on value added.

Notes: (a) These are value added by the industries. The value added by Discrete Manufacturing and Prog.Discr.Manufacturing are estimated by multiplying the value added of the manufacturing sector by the index of discrete product and index of percent amenable by automation.

As summarized in the table, the manufacturing industry's total cost of production could be reduced by $27.57 billion as a result of the application of programmable automation. The savings range from zero to 20 percent of the operating cost of the various industries and an overall savings of 5.6 percent of the operating cost of the entire manufacturing sector is indicated.

As shown in Table 12 the savings figure of $27.57 billion is about 9 percent of the value added of the manufacturing industry and about 14 percent of the value added of the discrete manufacturing industry.

B. IMPACT ON INTERNATIONAL TRADE

The central concern of the theory of international trade has been the principle of comparative cost. Due to serious balance of payments crises during the last five years, it has become apparent that the issue of U.S. trade competitiveness is a major national concern requiring an identification of the problems and potential solutions. Programmable automation could have significant impacts upon the U.S. balance of trade by improving the relative cost advantage of the U.S. manufacturing sector.

Total U.S. exports and imports amount to about $90 billion or 9 percent of the GNP; the exports and imports of manufactured products are about $38 billion each or around 40 percent of the total. U.S. imports accelerated most rapidly since 1965, at an annual percentage increase of 13.9; manufactured product imports increased at a rate of 19.6 percent. A major portion of manufactured imports are discrete products which are amenable to programmable automation. Table 13 lists some of the major discrete commodity groups and their imports in 1969.

Table 13

Imports of Discrete Products

Commodities	1969 Imports $ Million	1965-1969 Average Annual Rate of Growth
Road Vehicles & Parts	4,883.3	48.5
Electrical Household Equipment	127.5	46.8
Telecommunications Apparatus & Parts	1,005.9	33.8
Non-electric Power Generating Machinery	603.4	32.7
Electric Power Machinery	196.0	30.7
Metal Working Machinery	182.7	30.3
Office Machines	371.8	28.5
Electric Machinery & Apparatus	495.4	28.1

Source:
Competitiveness of U.S. Industries, Report to the President on Investigation, No. 332-65, Table 3.

The increasing imports reflect the loss in U.S. comparative advantage due to a sharp rise in labor cost during the last five years. Table 14 provides the relative increases in labor costs and export price increases for the U.S. and its major competitors.

Table 14

International Comparison of Labor Costs in Manufacturing

	Annual $ Increase in Mfg. Labor Cost 1965-1969	Export Price Increase 1965-1969
U.S.	16%	13%
W. Germany	10%	5%
France	3%	5%
Japan	2%	7%
United Kingdom	-3%	2%

- U.S. labor productivity rate has declined and has been half as much during 1965-69 as in 1960-64. Productivity gains in Japan equaled six times the U.S. rate between 1966-69.

- Other things remaining the same, it is indicated below that a possible reduction in index of unit export price of manufactured goods by only 6 percent will lower the 1971 manufacturing price index to the 1969-70 level at which time the United States was in a favorable trade position.

Index of unit (average export price of manufactured goods in 1971) is half+ plus	=	126.7
Six percent saving on costs due to feasible automation in manufacturing reduced the unit export price index to 126.7 x 0.94	=	119.10
The average unit export price in 1969-70+ plus	=	119.8

Source:
+*Economic Report of the President*, January 1972, Table 34, p. 152 (1964 = 100).

- Likewise, the 6 percent cost reduction in index of unit price will amount to an increase in the relative import prices of foreign manufactured goods, and hence a reduction in imports of all the other conditions and relationships of 1969-70 concerning U.S. international trade are met. Our preliminary estimates are shown below:

Imports of Manufacturing Goods in 1969

Imports from W. Germany, U.K., Italy, Belgium, and France+	5,845.2
Percent of total U.S. imports	27.7%
Expected decrease in imports from these five countries	528.3
Import from Japan+	4,360.0
Percent of total U.S. imports	20.7%
Expected decrease in imports from Japan	1,566.0
Expected decrease in imports from the above countries	2,094.3

Source:

1) +Competitiveness of U.S. Industries, Table 19, pp. 77-78, Table 2.

2) +Statistical Abstract of the U.S., 1971, Table 1239

- The dominance of manufacturing in the export sector clearly implies that U.S. international competitiveness could be improved substantially by 1) lowering the unit cost of domestic manufacturing goods, and 2) enhancing the rate of technological development. Programmable automation holds prospects for significant reductions in the production cost of particular discrete manufactured products as discussed in the previous sections.

IV. IMPACT UPON PRICE STABILITY

The wage-price spiral has become a major national concern. Our preliminary analysis indicates that labor costs have been increasing proportionally with other costs. Between 1960 and 1965 prices were relatively stable. The price spiral began in 1965 and continued through 1971 until price controls were imposed. Inflation will continue to be a major national concern. An examination of price trends by industry reveals that price increases in chemicals, farm products, and transportation equipment were below the national average for all commodities from 1960 to 1969. On the other hand, prices of metal and metal products, food processing, and especially machinery were much higher than the national average for all commodities. The trend relationships are depicted in Figure 4, and they point to a higher increase rate in machinery prices than the average for all commodities. As clearly illustrated in Figure 5, the annual rate of price changes for machinery increased steadily from 1964-1965 through 1968-1969, while others -- although rising (except for chemicals) -- do fluctuate.* Programmable automation could make major contributions toward U.S. price stability by reducing the rate of increase in price behavior of the discrete engineering manufacturing goods. The general price level of the economy is very sensitive to changes in the price level of these industries and vice versa. The sensitivity of relative price changes by each industry as a result of a change in general prices indicates that metal and machinery prices are more responsive than the other major manufacturing industries. For instance, based upon the past behavior of industry prices to the general price level, it has been shown that a general price increase of 5 percent will result in the following relative price changes:

*See Table 15 for data.

	Percentage of Change
Farm products	4.5%
Processed food	6.2
Chemicals	1.0
Rubber	3.3
Metal	6.9
Machinery	6.1
Furniture	3.3
Transportation Equipment	3.7

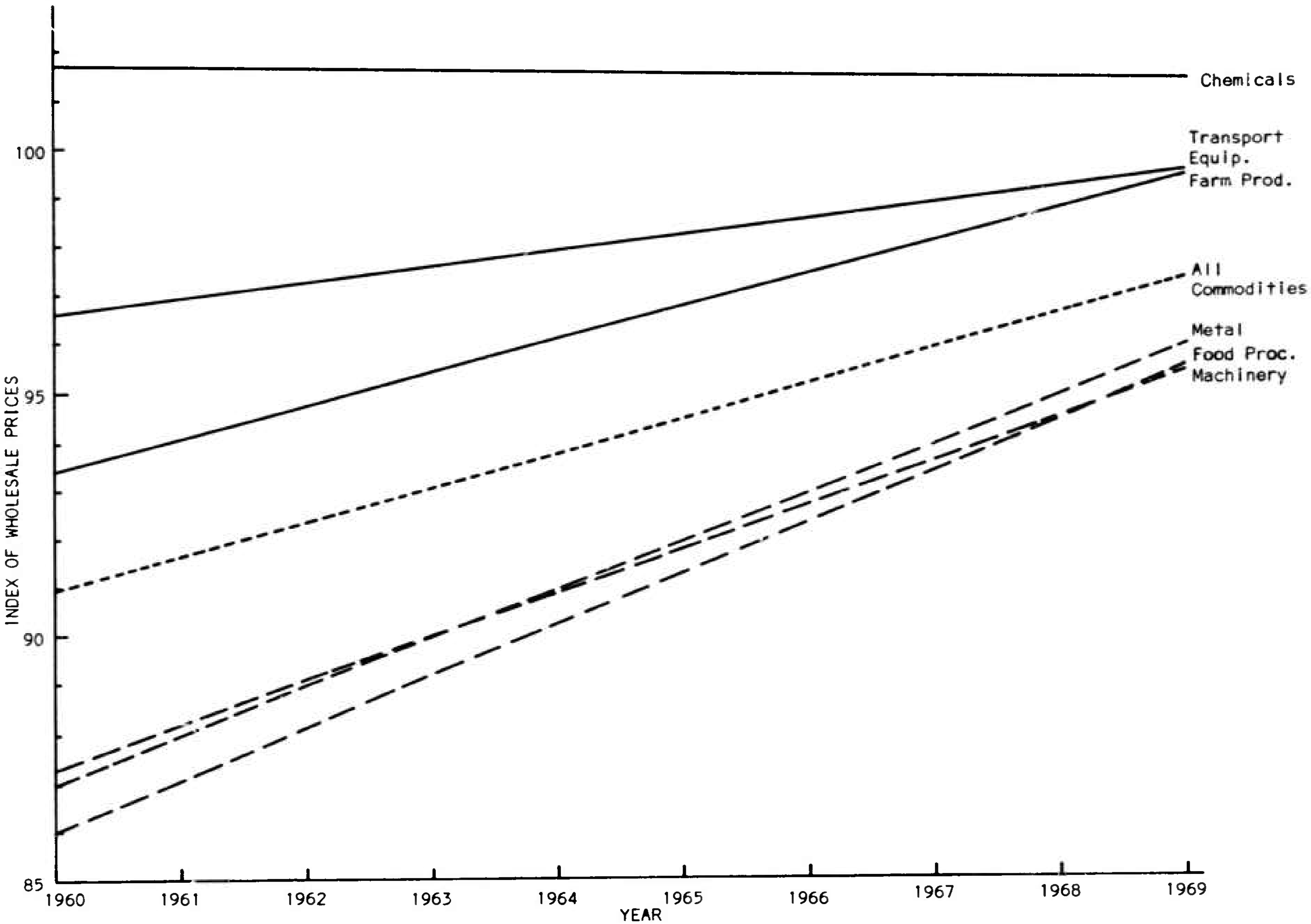

Fig. 4 - Wholesale price trends

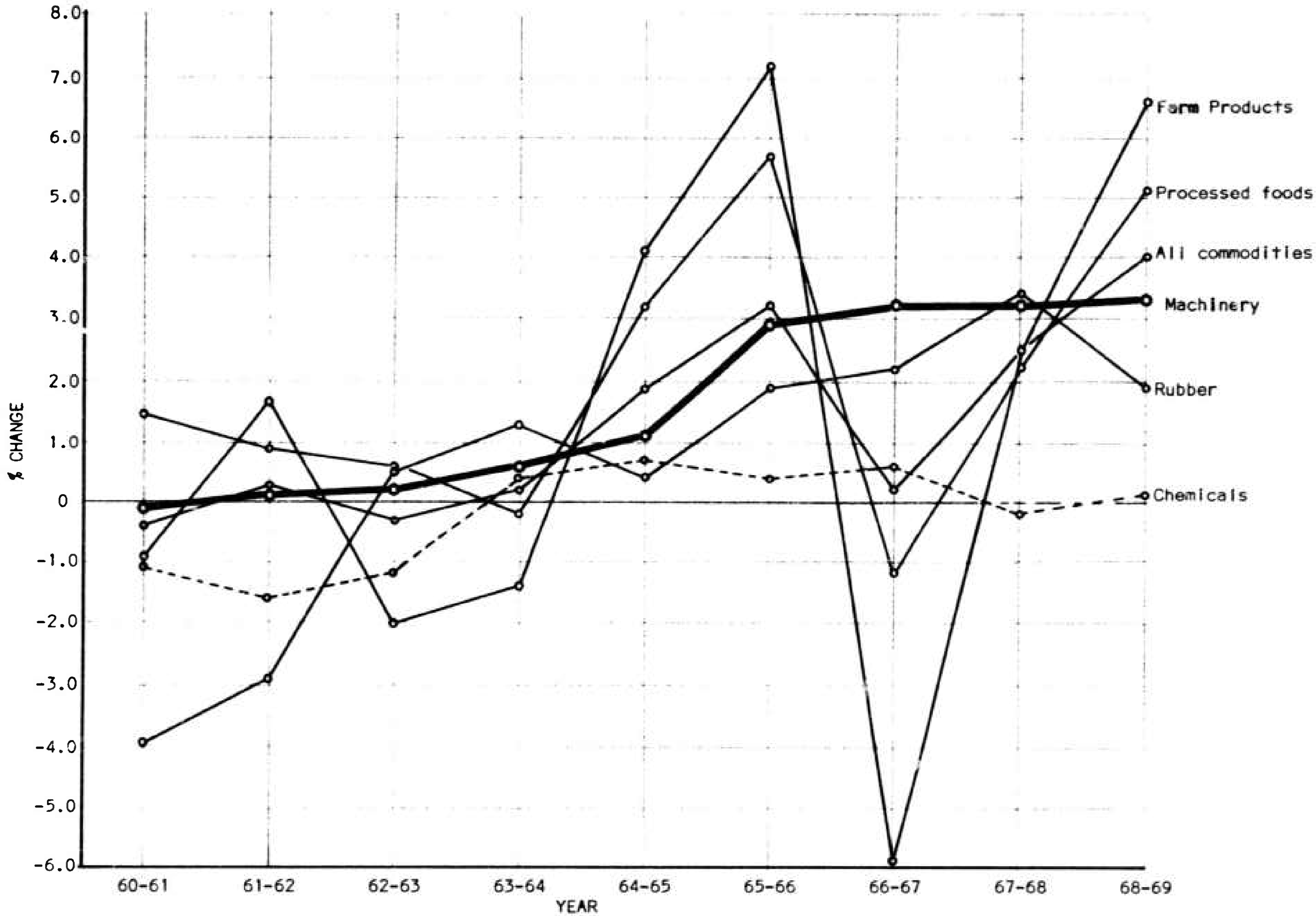

Fig. 5 - Annual change in wholesale price

Table 15

WHOLESALE PRICE FLUCTUATIONS

	Annual Change in Prices								
	60-61	61-62	62-63	63-64	64-65	65-66	66-67	67-68	68-69
All Commodities	-0.4	0.3	-0.3	0.2	1.9	3.2	0.2	2.5	4.0
Farm Products	-0.9	1.7	-2.0	-1.4	4.1	7.2	-5.9	2.5	6.6
Processed Foods	1.5	0.9	0.6	-0.2	3.2	5.7	-1.2	2.2	5.1
Chemicals	-1.1	-1.6	-1.2	0.4	0.7	0.4	0.6	-0.2	0.1
Rubber	-3.9	-2.9	0.5	1.3	0.4	1.9	2.2	3.4	1.9
Metal	-0.5	-0.7	0.1	2.5	2.6	2.4	1.2	2.6	5.9
Machinery	-0.1	0.1	0.2	0.6	1.1	2.9	3.2	3.2	3.3
Furniture x household durables	-0.6	-0.7	-0.7	0.4	-0.5	1.1	2.0	2.8	2.1
Transportation Equipment	-0.2	0.0	-0.8	0.5	0.2	0.1	1.4	2.8	2.0

Source:
Economic Report of the President, Table B-48, 1972.

V. IMPACT UPON EMPLOYMENT

Technological advances have varying degrees of impact on the quality of employment and its quantity, in the short and long terms.

1. The quantitative aspect of employment includes such factors as the size, composition and rates of employed, labor force, unemployed, the issues related primarily to income, pay rates, and employability which are in turn affected by education, age, color, sex, and other socioeconomic characteristics of the labor force.

2. The quality of employment and work ethics have become a significant social issue. The role of work in the quality of life has gained relevance and importance. In a study by the University of Michigan Survey Research Center, it was reported that a majority of the respondents ranked "good pay" fifth behind such other factors as "interesting work," "enough help and equipment to do the job."

The impact of any technological change upon the quality and quantity of employment produces mixed blessings, depending upon who is affected and in what manner. The workers displaced due to technology are adversely affected since they have to find other jobs and/or receive more training. Technological unemployment is a short run phenomenon. One study concluded that with respect to employment, automation is neither an unmixed virtue nor an unmitigated evil, depending on whether an economy is in a capacity-deficient labor-scarce or labor-abundant situation. It concludes as follows:

> To sum up, our analysis seems to warrant the forward-looking view that automation, while tending to entail structural technological unemployment, nevertheless will progressively serve the multipurpose of spurring output expansion pari passu with population growth, remedying labor shortage as a possible bottleneck to capacity growth, and enhancing leisure with income but without drudgery.*

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*K. K. Kurihara, "The Automatic Impact of Automation on Employment and Growth," Economic Internationale, Vol. 22, August 1969.

On the macrolevel, it has been claimed that technological improvements in the long run have created more, different, and better jobs. We believe that the impact of PA upon employment will not be much different than the impact of previous technological changes. In the light of an evolving socio-cultural value and better education, workers do not see virtue in routine, monotonous, and physically and mentally laborious jobs, especially in the grinding routine of the assembly line. A 1971 Gallup Poll of workers of all ages showed that 19 percent were displeased with their jobs.

Lately, auto workers have demanded increased participation in the decision-making role within plants. Job sharing or influencing production rate per number of employees has emerged as a labor management issue. This was exemplified in the UAW's striking of selected GM plants for specified periods during October 1972. Likewise, the labor strike at the General Motors Vega plant in Lordstown, Ohio, in 1971 was claimed to have been for better quality of work. A recent HEW report, "Work in America," identified two chief causes of job dissatisfaction: 1) loss of worker autonomy and sense of personal freedom; and 2) the introduction of conventional types of efficiency systems (e.g., fragmentation and compartmentalization) that placed workers under continuous supervision. Working on the "perfect line" is considered oppressive and dehumanizing. Another study which reviewed 138 recent cases dealing with technological change, involving labor union grievances brought against companies, found that 78 percent were awarded to the companies and only 22 percent to the unions. About 49 percent of the cases fell in the category of "employer had no right to combine jobs." On the basis of this study it would seem that the potential inhibition of new technological implementation imposed by labor unions would not be significant.*

*G. King, "Arbitration of Technological Change," Ph.D. Dissertation, University of Southern California (Economics), 1972, (unpublished).

The impact of PA would have to address both the quality and quantity of employment. Our preliminary analysis indicates that direct labor from routine work will decline substantially and the quality of employment will improve both in terms of better environment and better job challenge. Nevertheless, a great deal more research is required to assess the economic impact and the qualitative and quantitative effects in the short and long run.

VI. IMPACT UPON INDUSTRY STRUCTURE, LOCATION, AND ENVIRONMENT

Certain hypotheses about the impact of PA are briefly mentioned under a set of assumptions that will require analysis, testing, and verification.

A. THE INDUSTRY STRUCTURE

Historically, technological inventions and innovations have contributed to concentration of economic power in the hands of a few large corporations. Consequently, most important U.S. industries are dominated by a small number of corporations whose relative share of the output is vastly greater than the number of firms represented in the industry. This trend has been in contradiction to the Government's antitrust policy and to the promotion of competition, since it has been asserted in theory and practice that consumer welfare is better served under competitive than noncompetitive market conditions. Also, traditionally, it is hypothesized that large firms account for a greater share of inventions and innovations than small firms, due to their ability to finance research and development.

It is our hypothesis that PA could conceivably reverse this trend in the engineering manufacturing sector. This is exemplified by the computer software industry, whereby numerous competing firms have emerged, since the capital outlay requirements to start a new software firm is small. We conjecture that innovations and applications of the PA type do not depend upon the size of the firm but, rather, upon the stability of the market demand conditions, the degree of adaptability of PA to the production process, and the financial viability that the PA system could command, be it risk insurance through private means or some combination of public/private risk sharing.

It is conceivable that production service bureaus will develop and enable a host of small- and medium-size firms to draw upon the most modern production technologies on demand. With the considerable reduction in the share of direct and indirect labor input in the PA plant as compared to the conventional plant, the firm's production function will tend toward constant return to a wide range of firm sizes. It follows that mass production-type industries (increasing returns to scale) like petroleum, chemicals, etc., will not benefit by the PA production methodology as much as the decreasing returns to scale type industries such as those manufacturing discrete engineered products. Thus, PA is likely to benefit the small- and medium-size firms, and companies having lot size production runs. The optimal size of the firms will be determined by the size of market demand conditions and the technical nature of PA in relation to the size of the firm. Thus, it is hypothesized that the characteristics of PA contribute to the enhancement of competition and the promotion of consumer welfare.

B. URBAN/RURAL MIX

The secular migration of the population from rural to urban centers has created a wide range of rural economic and cultural blight and urban congestion, pollution, crime, and a host of associated social ills. One major reason for this migration is the availability of jobs in the urban centers. The magnitude and range of jobs are due to the location of industries in the urban centers. This locale is chosen partly for proximity to labor supply, since labor is a major cost component of manufacturing production. Although the above cause and effect relationships appear to contain circular reasoning, nevertheless, they are mutually interacting and the availability of labor supply does influence location decision, which, in turn, generates employment and thus in-migration. We have hypothesized that PA will reduce labor requirements substantially. Should this be the case, the firm's decision concerning location will alter as well.

The trade off will be between the transportation costs of a firm if it locates out in the country versus the costs associated with urban location such as real estate, rent, land, property and other local taxes, license fees, restrictive ordinances, pollution, etc. A case study of the comparative costs of manufacturing firms located in urban areas indicates that land and property tax expenses play an important role in location decision.* Our hypothesis is that if the supply of labor (the availability of labor) is taken out of the location decision model or if its role becomes insignificant, many firms may be enticed to locate outside urban centers. Such a trend will provide for balanced regional growth and improve the urban/rural mix for the better.

C. IMPACT UPON ENVIRONMENT

The unit cost of a hypothesized programmable factory has indicated that with PA, it is possible to reduce the labor as well as capitql and energy input, while producing the same output. This could easily be translated into a reduction of energy consumption in the process of production and, hence, reduction of a variety of pollutions (water, air, and land). Also, the better balance in the urban/rural mix of industry locales could contribute to the aesthetic and other quality of life indicators. Other possible influences of PA that may contribute to the quality of environment include reduction in transportation needs, in factory-space requirements, and in repair and defective products, and enhancement of consumer satisfaction.

*Andrew M. Hamer, "The Comparative Costs of Location of Manufacturing Firms in Urban Areas: A Boston Case Study," Harvard University, 1972.

IV. POLICY IMPLICATIONS

1. The preceding discussions included many assumptions, hypotheses and "soft" data. To the extent that these assumptions are based upon some of the future capability and performance of software and hardware computer, involving the nature of the firm, and the existence of the required institutional framework, a great deal of risk (the probability function of foreseen events) and uncertainty (the probability function of unforeseen events) do exist. For these reasons, it is necessary that the production characteristics and cost components of the discrete engineering manufacturing products be studied and representative characteristics be specified in terms of the size of the products, batch production rate and its relative share of the total, precision requirements, relative costs and time requirements of each step of production, alternative schedulings and other alternative simulations of production modes to determine optimization of factor inputs. Since 35 percent of the total DOD procurement is made by only ten firms, such an undertaking could be greatly facilitated. Table 16 and Table 17 below provide the procurement distribution and the number of contractors.

2. The dramatic savings claims and cost reductions indeed require a great deal more scrutiny both in terms of feasibilities (technical and economic) and practicality in terms of transfer of technology and adaptability into production operations of manufacturing enterprises. The history of the development of NC* and a great deal of other modern technological developments, especially new weapon systems heavily depended upon the Government's underwriting of the development and prototype costs. In two recent conferences on U.S.

*See Jack Rosenberg, "A History of Numerical Control 1949-1973: The Technical Development, Transfer to Industry, and Assimilation," Information Sciences Institute, University of Southern California, ISI/RR-73-3, October 1973.

Table 16

PERCENT OF DOD PROCUREMENT

Companies	FY 1969	FY 1970	FY 1971	FY 1972
1st	5.5%	5.9%	5.1%	5.1%
2nd	4.4	3.8	5.0	5.1
3rd	3.4	3.2	4.0	3.9
4th	2.9	3.0	3.7	3.7
5th	2.7	2.8	3.5	3.5
1 - 5	18.9%	18.7%	21.3%	21.3%
6 - 10	10.1	10.5	13.5	13.9
11 - 25	15.8	16.8	17.3	16.0
1 - 25	44.8%	46.0%	52.1%	51.2%
26 - 50	12.1	13.3	11.0	11.5
51 - 57	7.3	6.6	5.8	6.0
76 - 100	4.0	3.8	3.2	3.4
1 - 100	68.2%	69.7%	72.1%	72.1%

Source:

100 companies (companies receiving the largest dollar volume of prime contract awards) FY 1972, Department of Defense, 6 October 1972.

Table 17

THE TOP TEN CONTRACTORS FOR FY 1972
(in dollar volume of prime contracts)

Companies	In $ Billion*	% of Total
1. Lockheed	1.7	5.1
2. McDonnel-Douglas	1.7	5.1
3. General Dynamics	1.3	3.9
4. General Electric	1.2	3.7
5. Boeing	1.2	3.5
6. American Telephone	1.1	3.4
7. Grumman Corporation	1.1	3.4
8. United Aircraft	0.9	2.9
9. North American Rockwell	0.7	2.1
10. Hughes Aircraft	0.7	2.0

*These figures are rounded

Source:

Ibid.

productivity,* members of the industry expressed such interest in obtaining Government's leadership and assistance for spearheading joint research and development programs, especially in automation, minimizing duplication efforts, assistance in replacement of old equipment, some modification of anti-trust laws if U.S. business is going to be on the same footing as its foreign competitors, and improvements of productivity. In both of these conferences, the share of the Government's expenditures for the above purposes were estimated at $1 billion, although the reciprocal response of the industry, its nature of participation, degree of commitment and propriety requirements were not expressed.

The above issues are directly relevant to this study project and need to be studied in depth. Moreover, new and imaginative alternatives need to be advanced and explored as supplements to the existing incentive programs.

3. Another important area of policy implication is that of directing the research effort into those areas which would have the greatest impact in terms of saving across the board. It follows that there is a need to develop representative cost models for groups or categories of DOD product mix as well as for industry groups which would account for a large percentage of total procurement and production, respectively. In addition, the selection should take into consideration the possibility of spillover into industry since the methodology could as well be used in the production of non-DOD manufactured goods. Associated with these considerations are the problems of inflation, balance of trade, and the quality of employment. As discussed in the preceding section, PA could precipitate significant impacts upon these areas and, therefore, these factors ought to be explicitly considered as important criteria in support of the study project.

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*Conferences: "A National Inquiry into Productivity in Durable Goods Manufacturing," University of Massachusetts, (October 4-6, 1972) and "Manufacturing Productivity Conference," Washington, D.C., (October 11-13, 1972).

4. The United States' declining rate of manufacturing productivity was noted in 1965. There appears to have been a seven-year time lag between the recognition of that trend and attempts to take counter-measures to rectify the situation. Moreover, engineering program developments take several years from conception to its development and dissemination and wide use in industry (NC took twenty years).* These time lags indeed add up and the relevance of the point should not become lost. The U.S. unfavorable trade balance situation has not bottomed out yet. It will take considerable improvement in U.S. productivity before an equilibrium is re-established.

5. Governments, in a number of U.S. competitors, have already taken steps to augment their rate of automation and hence productivity. The following examples were cited in the Rand report.**

a. Forty companies in Japan have recently developed industrial robots whereas only nine have been developed in this country;

b. The U.S. Maritime Administration has recently spent $250,000 abroad for the purchase of a program for the design and cutting of large plates used in ship construction;

c. Sixty automatic paint spraying robots are in operation in the European applicance industry. There are none in the U.S.;

d. A national project costing $180,000,000 has just been funded in Japan for the development of general purpose automation. Nothing comparable is happening in the U.S. There is good cause to study the relevance of the above cases and others for U.S. policy implications.

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* In a Battelle Institute study, Science, Technology and Innovation (Februrary 1973), the average duration from conception to realization of ten innovations studied was 19 years.

** Rand report, op.cit.

APPENDIX A

I. SOURCES OF DATA

1. INDICES OF OUTPUT PER MAN-HOUR:

   Selected Industries, 1972 Edition, U.S. Department of Labor, Bureau of Labor Statistics, 1972.

2. COUNTY BUSINESS PATTERNS 1970:

   U.S. Summary, U.S. Department of Commerce, Bureau of the Census, 1971.

3. 1971 BUSINESS STATISTICS, U.S. Department of Commerce, Office of Business Economics, 1971.

4. ECONOMIC REPORT OF THE PRESIDENT, 1972

5. STATISTICAL ABSTRACT OF THE U.S. 1971:

   U.S. Department of Commerce, 1971.

6. U.S. INDUSTRIAL OUTLOOK, 1972 WITH PROJECTION TO 1980

7. INDUSTRY PROFILES, 1958-1969, U.S. Department of Commerce, 1971.

8. SHIPMENT OF DEFENSE-ORIENTED INDUSTRIES, 1970, MA-175(50)-1. U.S. Department of Commerce, 1970.

9. HIGHLIGHTS OF EXPORTS AND IMPORTS, July 1972, U.S. Department of C mmerce.

10. COMPETITIVENESS OF U.S. INDUSTRIES Tariff Commission Publication No. 473, April 1972.

11. THE BUDGET OF THE U.S. GOVERNMENT, Fiscal Year 1973.

12. REPRINT FROM BLS HANDBOOK OF METHODS, Chapter 11, Wholesale prices.

13. CURRENT INDUSTRIAL REPORTS, Department of Commerce, Bureau of the Census, Weekly.

14. PRODUCTIVITY AND THE ECONOMY, U.S. Department of Labor Bulletin, 1971.

15. ANNUAL SURVEY OF INDUSTRIES, U.S. Department of Commerce, Bureau of the Census.

16. CENSUS OF POPULATION, U.S. Department of Labor, Bureau of Labor Statistics.

17. CENSUS OF MANUFACTURERS, U.S. Department of Commerce, Bureau of the Census.

18. ECONOMIC HANDBOOK 1972-1973 of the Machine Tool Industry, National Machine Tool Builder's Association, 1972.

19. ANATOMY OF AN INDUSTRY, Institute of Science and Technology, University of Michigan.

20. INDICES OF OUTPUT PER MAN-HOUR:

Selected Industries 1939 and 1947-70, U.S. Department of Labor, Bureau of Labor Statistics, Bulletin 1692.

21. PRODUCTIVITY AND THE ECONOMY, U.S. Department of Labor, Bureau of Labor Statistics, Bulletin 1710.

22. ANNUAL EARNINGS AND EMPLOYMENT PATTERNS of Private Non-Agricultural Employees - 1965, U.S. Department of Labor, Bureau of Labor Statistics, Bulletin No. 1675, 1970.

23. MACHINERY AND ELECTRICAL EQUIPMENT MANUFACTURING, U.S. Department of Commerce, Business and Defense Services Administration.

24. OCCUPATIONAL OUTLOOK HANDBOOK, 1970-71 Ed., U.S. Department of Labor, Bureau of Labor Statistics, Bulletin No. 1650.

25. CORPORATION ON INCOME TAX RETURNS, Internal Revenue Service, 1968.

26. BUSINESS INCOME TAX RETURNS, Internal Revenue Service, 1968.

27. ENTERPRISE STATISTICS, U.S. Department of Commerce, Bureau of the Census, 1973.

II. BRIEF DESCRIPTION OF THE DATA

1: Table 1: 1971 employment, production workers, and non-production workers by 3 and 4 digit SIC codes.

Tables 2-80: Time series index of output per man-hour, output per employee (both production and non-production), man-hours, employment, and output for 3 and 4 digit SIC codes.

Also charts for the same information

2: By 2 digit SIC code, by states information on employment for 1969 and 1970.

3: The following time series information can be obtained from various tables:

Employment by industry;
Employment earnings;
Foreign trade statistics;
Finance statistics;
By industry, production, consumption, exports, imports, etc.

4: Annual publication with statistical data on income, employment, foreign trade, prices, etc.

5: See Table of Contents

6: By SIC code for 1967-1972 data on value of shipment, value added (by employment status), total employment, production workers, wholesale price index, number of establishment, annual growth rates.

7: By 3 and 4 digit SIC codes time series data from 1958 to 1969 on:

Employees
Production workers
Payroll
Wages of production workers
Value of shipment
Value added

Cost of materials
Capital expenditures
Certain ratios like value added
Per worker, man-hour, wages,
per worker, etc.

8: List of defense-oriented industries (By SIC code and geographic area for 1969 and 1970):

Value of shipment
Value added
Employment
Shipments to DOD, NASA, AEC
and other agencies
Prime contract
Sub-contract
Wages, payroll
Production workers
Material costs
Contractual Services and other costs

9: Time series data on merchandise trade by commodity groups and by country.

10: Time series data on U.S. exports and imports by commodity groups, exports-imports price indices unit labor cost.

14: Labor productivity by commodity groups

17: Volume I contains summary; by 2 digit SIC codes the statistics on the following are available:

Employment
Number of establishments
Wages
Value added
Costs of material

Value of shipment
Capital expenditure
Inventories
N.I. originating
Expenditure on plant, machinery, equipment, etc.
Water consumption
Fuel consumption
Work in process
Finished goods

Volume II, etc., give details.

25 & 26: Data based on income tax returns by business and corporations:

Business receipts
Assets
Income Tax
Cost of goods sold
Dividends
Size distribution of business by asset, business receipts,
Cost breakdown by labor and material.

27: A very recent detailed and comprehensive source of data in business, minerals, manufacturing, and combinations of the above.

III. USES OF THE DATA

The data available from the various sources can be used to make the following types of analyses:

B-1: Statistical (Computational) Analysis

(1) Computation of value added, value of shipment, wage rate, cost of material, etc., for each SIC industry on per capita, per-worker basis.

(2) Computation of relative importance of each SIC industry to the economy measured in terms of value added, value of shipment, employment, profit, etc.

(3) Role of these SIC in foreign trade evaluated in terms of exports, imports.

(4) The unit labor cost trend and price trend for each SIC industry.

(5) Productivity growths: man-hour productivity, labor productivity, etc.

(6) Relative picture of cost material to material for each SIC industry.

B-2: Economic Analysis

(1) Estimation of wage-price trend and Phillips curve analysis.

(2) Estimation of share of labor and capital in total output.

(3) The trend of capital-labor substitution and estimation of contribution of technology upon productivity (measured as residue).

(4) Derive the cost curve indirectly (using duality approach).

(5) Production function and its shifts due to technological change.

B-3: What is Not Possible with the Above Data:

(1) Estimation of cost breakdown by production steps.

(2) Estimation of feasibility of innovating certain production steps.

IV. NEED FOR FURTHER DATA

(1) On a case study basis, breakdown of costs by functionaries (production steps) and cost components. Partial information of this type can be obtained from CIR.

(2) From Census of Population:
the distribution of working force between different job types are to be matched with industry type to estimate the job distribution.

V. EXPECTED RESULTS FOR THE PROJECT

(1) Estimation of cost breakdown by cost components in various production steps.

(2) Percentage distribution of employment by job type (by SIC, probably).

VI DATA AVAILABLE FROM CENSUS MANUFACTURING

1. Materials -- by 4-digit SIC Code -- both pounds and dollar value.

   Very detailed breakdown of material.

2. Fuels and Energy:

   By 4-digit SIC Code:

   Quantity and dollar value.

   Energy: Gas, electricity

   (cu.ft.) (millions KW)

3. Water: Intake, user treatment, and discharge.

   By 4-digit SIC Code.

   Quantity of water.

4. Production Workers: by size of firm

   All employees: 4-digit SIC Code;

   4 man-hours, payroll, and wages.

5. Value added, Value of shipments by 4-digit SIC Code

6. Value of inventories:

   A. Finished production

   B. Work in Process

   C. Material Supplier, etc.

7. Capital Expenditure (new)

   A. Structures and addition to plants

   B. Machinery and equipment.

8. Fixed non-residential business capital

   A. Structuring

   B. Equipment

   C. Depreciation

   D. Cost of capital: depreciation + interest or "rental cost"

Appendix B

BIBLIOGRAPHY

on

PRODUCTIVITY, TECHNOLOGY, AND AUTOMATION

Agapos, A. M. and L. E. Gallaway, "Defense Profiles and the Renegotiation Board in the Aerospace Industry," Journal of Political Economy, September-October, 1970, pp. 1093-1105.

Ardolini, C. W., "Output Per Man-hours in Selected Industries," Monthly Labor Review, Vol. 93, March 1970, pp. 54-55.

Arrow, K. J., "Economic Welfare and the Allocation of Resources for Invention," in R. R. Nelson (ed.), The Rate and Direction of Invention Activity (Princeton: Princeton University Press, for the National Bureau of Economic Research), 1962.

Arrow, K. J., "Classificatory Notes on the Production and Transmission of Technological Knowledge," American Economic Review, Vol. LIX, May 1969, pp. 29-35.

Beach, E. F., "Automation in Perspective," Applied Economics, June 1971, 3(2), pp. 147-152.

Bekman, M. J., R. Sato and M. Schupack, "Alternative Approaches to the Estimation of Production Functions and Technological Change," International Economic Review, February 1972, pp. 33-52.

Bright, J. P., "The Impact of Automation in the Work Force," Automation and Management, Graduate School of Business, Harvard University, Cambridge, Massachusetts, 1968, pp. 170-188.

Bright, J. P., "Evaluating Signals of Technological Change," Harvard Business Review, January-February 1970, pp. 62-70.

Bright, J. P., "New Consideration in the Financial Justification of Automation."

Brown, M., On the Theory and Measurement of Technological Change (New York: Cambridge University Press), 1968.

Carter, A. P., Structural Change in the American Economy, Harvard Studies in Technology and Society (Cambridge: Harvard University Press), 1970.

Chang, W. W., "The Neoclassical Theory of Technical Progress," American Economic Review, December 1970.

Cheng, J. M., "Technical Change Measurement Under the Economic Model, Including Neutral and Embodied Technology," Southern Economic Journal, October 1970, pp. 215-217.

Danhof, C. H., Government Contracting and Technical Change, The Brookings Institution, 1968.

De Leeuw, "The Demand for Capital Goods by Manufacturers: A Study of Quarterly Time Series," Econometrica, Vol. 30, July 1962, pp. 407-423.

Denison, D. D., The Use of Learning Curves and Statistical Factors in Estimating Direct Engineering Man-hours for Missile and Space Systems, USC Thesis, 1965.

Denison, E. F., The Sources of Economic Growth in the United States and the Alternatives Before Us (Ed.), 1962.

Doctors, Samuel I., The NASA Technology Transfer Program: An Evaluation of the Dissemination System (Praeger Publishers), 1971.

Doctors, Samuel I., The Role of Federal Agencies in Technology Transfer (Cambridge, Mass: M.I.T. Press), 1969.

Fabricant, S., "Basic Facts on Productivity Change," Occasional Paper No. 63 (New York: National Bureau of Economic Research), 1959.

Feller, I., "Production Isoquants and Technical Change," Quarterly Journal of Economics, February 1972, pp. 154-161.

Ferguson, C. E. and J. R. Moroney, "Efficient Estimation of Neoclassical Parameters of Substitution and Biased Technological Progress," Southern Economic Journal, October 1970, pp. 125-131.

Flueckiger, G., "Observation and Measurement of Technological Change," Explorations in Economic History, Winter 1971-72, pp. 145-177.

Gallant, A. R., "A Note on the Measurement of Cost/Quality Relationships in the Aircraft Industry," Journal of American Statistical Association, Vol. 63, December 1968, pp. 1247-52.

Ghosh, A., (Expts. with I-O Models - An Application to the Economy of the U.K., 1948-55), (Cambridge, Mass: M.I.T. Press), 1964, Monograph 9.

Gold, B., N. S. Pierce and G. Rosegger, "Diffusion of Major Technological Innovations in U.S. Iron and Steel Manufacturing," Journal of Industrial Economics, July 1970, pp. 218-241.

Grossman, Edward and Stephen Laner, The Impact of Technological Change on Manpower and Skill Demand: Case Study Data and Policy Implications, University of California Berkeley, California, February 1969.

Gronber, W. H. and D. G. Marquis (Ed.), Factors in the Transer of Technology, (Cambridge, Mass: M.I.T. Press), 1969.

Harberger, A. C., "Survey of Literature on Cost-Benefit Analysis for Industrial Project Evaluation," Evaluation of Industrial Projects, Vol. 1, United Nations, (New York), 1968, HY 522.

Harberger, A. C., "Investment in Man vs. Investment in Machines: The Case of India," in C. A. Anderson and M. J. Bowman (eds.), Education and Economic Development, YH 516.

Hitch, C. J., and R. N. McKean, "Efficiency in Military Decisions," The Economics of Defense in the Nuclear Age, Chapter 7.

Hogan, W., "Technical Progress and Production Functions," Review of Economics and Statistics, November 1958, pp. 07-411.

Huebes, J., "On the Reliability of Empirical Estimation of Technological Change and the Elasticity of Substitution," German Economic Review, 1971, pp. 353-364.

Jorgensen, D. W. and Z. Griliches, "Division Index Numbers and Productivity Measurement," Review of Income and Wealth, June 1971, pp. 227-229.

Jorgensen, D. and Z. Griliches, "The Economics of Productivity Change," The Survey of Current Business, 1969.

Jorgenson, D. W. and J. A. Stephenson, "The Time Structure of Investment Behavior in U.S. Manufacturing, 1947-60," Review of Economics and Statistics, Vol. 49, 1967, pp. 16-27.

Kamien, M. I. and M. L. Schwartz, "Induced Factor Augmenting Technical Progress from a Microeconomic Viewpoint," Econometrica, October 1969, pp. 669-684.

Kendrick, J. W., Productivity Trends in the U.S. National Bureau of Economic Research, No. 71 (Princeton University Press), 1961.

Kennedy, C. and A. P. Thirlwall, "Technological Progress: A Survey," Economic Journal, March pp. 11-72.

Krasouskii, V., "Technical Progress and Capital Investment Problems," Problems of Economics, September 1970, pp. 3-22.

Kurihara, K. K., "The Antinomic Impact of Automation on Employment and Growth," Economica Internazionale, Vol. 22, August 1969, pp. 423-433.

Kuznetz, Simon, Economic Growth and Structure, (New York: W. W. Norton & Co., Inc.), 1965.

Mansfield, Edwin, The Economics of Technological Change (New York: W. W. Norton & Co., Inc.), 1963.

Mansfield, Edwin, Industrial Research and Technological Innovation: An Econometric Analysis (New York: W. W. Norton & Co., Inc.), 1968.

Mansfield, Edwin et al., Research and Innovation in the Modern Corporation (New York: W. W. Norton & Co., Inc.), 1971.

Mead, W. J., "Energy Policy and the Environment," Energy Project (Ford Foundation), April 2, 1973.

Massell, B., "Capital Formation and Technical Change in U.S. Manufacturing," Review of Economics and Statistics, May 1960, pp. 182-188.

Massell, B., "A Disaggregated View of Technical Change," Journal of Political Economics, December 1961, pp. 547-557.

Nadiri, M. I., "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey," Journal of Economic Literature, Vol. 8, December 1970, pp. 1137-1177.

Nordhaus, W. D., "An Economic Theory of Technological Change," American Economic Review, Vol. LIX, May 1969, pp. 18-28.

Nordhaus, W. D., Invention, Growth, and Welfare: A Theoretical Treatment of Technological Change (Cambridge, Mass: M.I.T. Press), 1969.

Nordhaus, W. D., "The Recent Productivity Slowdown," Brookings Papers on Economic Activity, No. 3, 1970.

Pegrum, D. F., "The Impact of Changing Technology on National Transportation Policy in the United States," Rivista Internationale di Science Economiche e Commerciali, March 1970, pp. 216-236.

Piore, J. J., "The Impact of the Labor Market Upon the Design and Selection of Productive Techniques within the Manufacturing Plant," Quarterly Journal of Economics, Vol. 82, November 1968, pp. 602-620.

Popper, K., The Logic of Scientific Discovery (Revised Ed.), Hutchinson (London), 1961.

Ray, G., "The Diffusion of New Technology: A Study of Ten Process Industries," National Institute of Economic Review, May 1969, pp. 40-83.

Revankar, N. S., "Capital-Labor Substitution, Technological Change and Economic Growth: The U.S. Experience, 1929-1953," Metroeconomica, May-August 1971, pp. 154-176.

Rogers, Everett, Diffusion of Innovation (New York: Free Press), 1962.

Robinson, J., "The Classification of Innovations," Review of Economic Studies, Vol. 5, February 1938, pp. 139-142, reprinted in Stiglitz-Uzawa.

Salter, W.E.G., Productivity and Technical Change (Cambridge University Press), 2nd Ed., 1969.

Samuelson, P. A., "A Theory of Induced Innovation Along Kennedy-Weisacker Lines," Review of Economics and Statistics, Vol. XLVII, November 1965, pp. 343-356.

Sato, R., "The Estimation of Biased Technological Change and the Production Function, International Economic Review, June 1970, pp. 179-208.

Scott, Ellis L. and R. W. Bolz (Ed.), Automation and Society, The Georgia-Reliance Symposium, Athens, Georgia, 1969.

Shell, K., "Toward a Theory of Inventive Activity and Capital Accumulation," American Economic Review, May 1966.

Smith, W.J.J. and D. Creamer, R&D and Small-Company Growth: A Statistical Review and Company Case Studies, National Industrial Conference Board, 1968.

Solow, R. M., "Technological Change and the Aggregate Production Function," Review of Economics and Statistics, August 1957.

Taubman, P. and P. Gollschalk, "The Average Work Week of Capital in Manufacturing," Journal of American Statistical Association, September 1971, pp. 448-455.

U.S. National Committee on Technology, Automation and Economic Progress, "Technology and the American Economy," U.S. Government Printing Office: Washington, D.C., 1966

Technology and the American Economy, U.S. Government Printing Office, Vol. 1, February 1966.

Vernon, Raymond (ed.), The Technology Factor in International Trade, N.B.E.R. (Columbia University Press), 1970.

Wagoner, H.D., The U.S. Machine Tool Industry from 1900 to 1950 (Cambridge: M.I.T. Press), 1968.

Zndak, L.S., "Productivity, Labor Demand and Cost in a Continuous Facility," The Journal of Industrial Economics, Vol. 18, July 1970, pp. 255-74.

Appendix C

RELEVANT MACROECONOMIC MODELS

Models	General Characteristics
GE Model	The model uses factor analysis and forecasts profit and sales by 4-digit SIC. Additional forecast is possible for costs, productivity, and capacity utilization. It is not a structural model.
Wharton Econometric Forecasting Model	Uses simultaneous equations and provides breakdowns by industry including forecasts of capacity utilization, productivity, and outputs.
Office of Business Economics (OBE), Dept. of Commerce	Uses simultaneous equations for macroeconomic forecasts.
Fair Model, Princeton University	Simultaneous equations and auto regression correlation methods are used. It is more aggregated than the Wharton and OBE models.
Data Resources, Inc. (DRI)	Block-Recursive - twenty equations are determined recursively for input into an 80-equation block. It has its own data base of 700 time series and produces 81 industry sectors corresponding to 1963 input/output tables. The emphasis is on forecasting microeconomic variables.
Federal Reserve Bank of St. Louis	Recursive model. It is primarily a monetary model.

Models	General Characteristics
RSQE Forecasting University of Michigan	Simultaneous equations are used and forecasts are made of the National Income Account (disaggregated).
Chase Econometric Associates, Inc.	Simultaneous equations are used providing quarterly forecasts of macro-economic variables and 80-industry annual forecast of profits, productivities, costs, and capacity utilization.
Brookings Institution	Uses simultaneous equations (225) providing semi-annual forecasts of the manufacturing and non-manufacturing sectors. No industry breakdown is given.
FRB-MIT Model	Simultaneous equations are used and relates the monetary sector to key macroeconomic variables.
IBM Dept. of Economics	Quarterly and annual models using simultaneous equations and input/output models. They provide forecasts of the National Income Accounts. The I/O model provides industry shipments in 1958 dollars.
Bureau of Labor Statistics Employment Model	Draws upon OBE model to project labor productivity and technological change to 1980 (Based upon 1958 I/O tables), and employment projection based upon 1963 I/O tables.

Appendix D

Relevant References in Simulation and Modeling of Production Plants

1. Anderson, D. R., B. D. Sellers, and M. M. Shamma, "Simulation of Sequential Production Systems with In-Process Inventory," Proceedings of the Sixth Winter Simulation Conference, 1973, pp. 85-92.

2. Barten, K., "A Queuing Simulation for Determining Optimum Inventory Levels in a Sequential Process," Journal of Industrial Engineering, Vol. 8, 1962.

3. Conway, R. W., et al., An Experimental Investigation of Priority Assignment in a Job Shop, RM-3789-PR, The Rand Corporation, Santa Monica, California, 1964.

4. Heimburger, D. A., "A Cased Goods Conveyor Simulator," Proceedings of the Sixth Winter Simulation Conference, 1973, pp. 112-117.

5. Kwo, T. T., "A Theory of Conveyors," Management Science, Vol. 6, 1958, pp. 51-71.

6. Lientz, B. P., "On Non-parametric Model Intervals," SIAM Journal of Applied Mathematics, 1971.

7. Maggard, M. J., W. G. Lesso, G. L. Hogg, and D. T. Phillips, "Using an Extended Version of GERT to Simulate Priority and Assignment Rules in a Limited Job Shop Environment," Proceedings of the Sixth Winter Simulation Conference, 1973, pp. 274-288.

8. Narot, Y. R., "An Experimental Investigation and Comparative Evaluation of Priority Disciplines in a Job Shop-like Queuing Network," Research Report, University of California at Los Angeles, California, 1963.

9. Nelson, R. T., "Labor and Machine Limited Production Systems," Management Science, Vol. 13, 1967, pp. 648-671.

10. Phillips, D. T. and P. W. Skeith, "Ordered Entry Queuing Networks with Multiple Servers and Multiple Queues," AIIE Transactions, Vol. 1, 1969, pp. 333-342.

11. Pritsker, A.A.B., "Applications of Multichannel Queuing Results to the Analysis of Conveyor Systems," Journal of Industrial Engineering, Vol. 17, 1966, pp. 14-21.

12. __________, "Remarks on Simulation," Proceedings of the Sixth Winter Simulation Conference, 1973.

13. __________, Scientific Inventory Management (Englewood Cliffs, New Jersey: Prentice-Hall, Inc.), 1963.

14. Stuebing, R. C., "Monte Carlo Simulation of Full Case Conveying Systems," Digest of Second Conference on Applications of Simulation, 1968.

Note: For an elaborate bibliography on this and related subjects see Annette Harrison, Bibliography on Automation and Technological Change and Studies of the Future, The Rand Corporation, P-3365-4, March 1971, Santa Monica, California.

INPUT/OUTPUT BIBLIOGRAPHY

Chenery, H. B., and P. G. Clark, Interindustry Economics, New York, J. Wiley and Sons, 1959.

Dorfman, Robert, "The Nature and Significance of Input/Output," Review of Economics and Statistics, Vol. 36, May 1954.

Hirsch, W., et al., "Applications of Input/Output Techniques to Urban Life Indicators," Kyklos, 1971.

Johansen, Leif, A Multi-Sectoral Study of Economic Growth, Amsterdam, North-Holland Publishing Company, 1960.

Leontief, Wassily W., Studies in the Structure of the American Economy, New York, Oxford University Press, 1952.

__________, The Structure of the American Economy, 1919-1939, 2nd Edition, New York, Oxford University Pressy, 1951.

__________, Input/Output Economics, New York, Oxford University Press, 1966.

__________, "Environmental Repercussions and the Economic Structure," Review of Economic Studies, August 1970.

Miernyk, W. H., The Elements of Input/Output Analysis, New York, Random House, 1965.

National Bureau of Economic Research, Input/Output Analysis: An Appraisal, Studies in Income and Wealth, Vol. 18, Princeton University Press, New Jersey, 1955.

United States Department of Labor, Indices of Output Per Man-Hour Selected Industries, U.S. Government Printing Office, Washington, D.C., 1972.

Watson, D. A., "An Input/Output Approach to Environmental Problems," Oregon Business Review, January 1972.