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COMPUTERS AND MANUFACTURING PRODUCTIVITY

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SPECTRUM SERIES

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Ronald K. Jurgen

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Foreword

The ideal product would be one that has a seemingly endless life span, perhaps like Bayer aspirin. One could automate the production of such a product to the nth degree. High technology products, however, have a finite life span, and often undergo improvements in design before they become obsolete. Most experience nowhere near the uninterrupted production runs that aspirin enjoy.

Today we seek to integrate highly efficient and reliable standard machine tools into a unique configuration to produce a particular product for a limited time. Such a configuration should be able to accommodate modest variations of a product within a general class.

The computer is the ideal medium to integrate tools into such a system. However, manufacturing engineers know they've barely scratched the surface in applying computers. Their full exploitation in manufacturing means not only their use to link machines so that they transport both parts and data between them efficiently, but also the joining into one unified system of computer-aided design (CAD), computer-aided planning (CAP), computer-aided production planning (CAPP), and computer-aided manufacturing (CAM). If CAM is a challenge, then its integration with CAD, CAP, and CAPP is an order of magnitude more complex.

Nevertheless, important progress has been made, and the industrial world's movement toward more fully automated enterprises is very real. The technical accomplishments and institutional issues involving computers in manufacturing are the subjects of this volume. It represents the second volume in the *Spectrum* series of IEEE PRESS books, following closely on the heels of the successful "Next Generation Computers."

Donald Christiansen
Editor and Publisher, *IEEE Spectrum*

Preface

The lion's share of worldwide industrial markets goes to those companies with the manufacturing know-how to achieve high productivity levels. Technological innovation in manufacturing, as opposed to pure technological research, is one way to achieve high productivity. Japan, for example, has amply demonstrated how technology developed in the United States can be applied innovatively. More recently South Korea has demonstrated that it can be a major competitor of Japan in the manufacture of automobiles and electronic entertainment products.

One prime key to increased manufacturing productivity is the efficient application of computers and computer-controlled systems like CAD-CAE-CAM, robots, programmable controllers, materials handling equipment, and machine vision. The judicious use of these systems in a company with high labor costs can help offset the advantage of low labor costs at competing companies. A company has a true competitive edge when it has both low labor costs and efficient applications of computers. This assumes, of course, that the combination produces quality products.

What emerges from this shift in industrial strategy is that probably no company can any longer hope to compete effectively in world markets without increasing productivity through modern computer techniques. This does not mean that the computer is a panacea, but until something better comes along, it provides the most effective means to the end. That concept is the basis for this book. It aims to show why computer systems are important in today's industrial environment and how they can be applied successfully.

This book contains articles by experts and leaders in industry, government, and academia as well as by the *IEEE Spectrum* editorial staff. Part I focuses on productivity with major emphasis on what electrotechnology, management, and government can do to improve it. Distinguished authors in this section, which was published as a special issue of *IEEE Spectrum*, include Jordan J. Baruch, former Assistant Secretary of Commerce for Science and Technology; J. Fred Bucy, former president of Texas Instruments; Jay W. Forrester, Germeschausen Professor at the Massachusetts Institute of Technology; and Jacob Rabinow, former chief engineer at the National Engineering Laboratory of the National Bureau of Standards.

Part II, on manufacturing's role in productivity, provides a bridge between the material on productivity in Part I and that on data-driven automation in Part III. Here most of the articles come from such prestigious organizations in the United States as the National Academy of Engineering and the Office of Technology Assessment.

Part III, also based on a special issue of *Spectrum*, addresses data-driven automation, with major emphasis on the flow of data throughout an enterprise, the software and hardware that enable automation of the enterprise to take place, and the social implications and education problems involved in making data-driven automation work.

Part IV presents selected articles from *Spectrum* that cover a variety of ways to implement automation. The 10 articles, both *Spectrum* staff-written and expert-bylined, add further knowledge of how computers and computer-like products are increasing productivity in specific industry applications.

The two articles in Part V highlight the versatility of the programmable logic controller, while those in Part VI stress that of the industrial robot. Most of the articles here are based on papers given at the Society of Manufacturing Engineers meeting known as Robots 9.

Finally, Part VII gives insight into a major problem in the computer modernization of production facilities: the inability of various products and systems from different manufacturers to communicate with one another. The many facets of this complex problem are addressed as well as possible solutions, among them the General Motors Manufacturing Automation Protocol.

All of the articles in this book that were previously published in *Spectrum* were written and edited for nonspecialists in the particular areas addressed. Most, however, have sufficient depth to be of interest to the specialists. The "To probe further" section at the end of each article aids readers who wish to study a specific topic in greater depth.

This book is the culmination of the work of many individuals. In addition to the contributions of the authors of the various articles, many expert reviewers devoted time in their busy schedules to help keep the authors on the right track. The editor is indebted to both authors and reviewers.

Ronald K. Jurgen

Contents

Part III. Data-driven automation (*IEEE Spectrum*, May 1983) . . . 89

Part IV. Implementing automation . . . 153

Part V. Programmable logic controllers . . . 211

Part VI. Robots to the rescue 221

Part VII. The interface problem 267

Part I

PRODUCTIVITY

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PRODUCTIVITY

Some say, "Jobs are at stake." "Our very quality of life is in jeopardy." The speakers are no mere prophets of doom; their growing ranks include leaders of government, industry, and academia as well as social and physical scientists and, last but not least, engineers. The common target of their concern is productivity.

Throughout the industrialized world, productivity as measured by conventional formulas has been tailing off. It's not that the United States, Japan, Europe, and the U.S.S.R. are reporting absolute declines, but post-World War II productivity growth trends have not held up.

In the United States, for example, productivity growth in the 1970s was one half of what it was over the previous two decades. Further, the U.S. industrial leadership position relative to that of other industrialized nations (particularly Japan and West Germany) has clearly eroded. In steel, Japan has surpassed the United States in productivity measured in output per employee-hour. In consumer electronics, the vast portion of subassembly work by U.S. color TV makers has shifted to such countries as Taiwan, Korea, and Mexico. And even in computers—long the domain of U.S. industry—Japan is making major strides toward sales competitiveness.

But Japan itself has seen its previously unrivaled productivity growth rate founder of late and, for the first time in decades, the Japanese corporate giants have found it difficult to guarantee lifetime jobs to their employees. Similarly, the powerful West German economic machine has begun to falter. The question all this raises is: Are we merely seeing in these productivity setbacks the effects of the recent worldwide recession, or are we seeing a grander pattern based on a decline in technological innovation, a lack of farsighted economic policies, or a combination of factors?

The first set of papers that follow in Part I look at the productivity problem from several angles. First an attempt is made to define the issues—what is meant by "productivity," what evidence exists that traditional growth trends are imperiled if not already "by the board," and what key elements (social, fiscal, governmental, and, of course, technological) have an impact on productivity growth rates.

Authors of three of the articles in this section agree that the future of innovation is in peril. Since innovation and productivity form a closed loop, they say, productivity cannot grow without innovation. And without productivity growth, the capital necessary to spur innovation will not exist.

The section on electrotechnology to the rescue addresses how productivity can be increased in various ways. One of the most elegant and promising is through innovative design of product. One author describes how the integrated circuit is a classic example of this approach. Another author observes that computerized systems for machine tools can minimize in-process inventory, lead time, direct and indirect labor, tool changing and setups, while maximizing equipment utilization and flexibility.

Technological innovation, if it is to be completely successful, must be nurtured and protected as it evolves through several stages. Hurdles will appear at the point of conception, during development, in production, and in the marketplace. The section on management to the rescue underscores this premise.

Government clout, when used wisely, can have an extremely positive effect on productivity. The final section here describes what government can do. The authors stress that what seems to be needed, and is already in operation in some countries, are means for getting government and business to work together toward the common goal of increasing productivity.

Ellis Rubinstein Senior Associate Editor

DEFINING THE GAME

Who's worried about productivity? We all should be, if we're to believe IEEE Fellows J. Fred Bucy, Jacob Rabinow, and Jordan Baruch. These three men operate in vastly different environments with equally diverse concerns. Dr. Bucy, as president of Texas Instruments, is a "captain of industry"; Dr. Rabinow, chief research engineer at the National Engineering Laboratory for the U.S. National Bureau of Standards, is one of the great, independent inventors; Dr. Baruch, Assistant Secretary of Commerce for Science and Technology, has much to do with the development of governmental technology policy. But all three agree that the future of innovation is in peril.

How does this relate to productivity? Innovation and productivity form a closed loop. Without innovation, productivity growth cannot occur; without productivity growth, the capital necessary to spur innovation will not exist. And without both innovation and productivity increases, according to these men, the very quality of our lives must decline!

The following 19 pages of this special *Spectrum* issue on productivity provide a forum for expert authors to define the issues—to tell us what productivity is, how it's measured, what its growth trends have been and are likely to be, and what all this means should the trends continue without any special effort to affect them.

For the most part, this section depicts a gloomy scenario, but, in the interest of a full debate, one group of contributions by expert authors takes issue with the assumptions and conclusions upon which the bulk of this special issue is based—those that revolve around current fears that productivity is on the decline.

Why productivity is important

In a little noticed sentence in the 1978 Economic Report of the President of the United States, the U.S. Council of Economic Advisors states that the slowdown in productivity growth in the United States is "one of the most significant economic problems of recent years." The slowdown affects almost every major issue facing U.S. citizens—the U.S. trade balance, the expansion of inflation, the number of jobs available, the very quality of life. And yet, this phenomenon has attracted insufficient attention among the nation's policy makers.

The slowdown has been underway since the late 1960s. After World War II, for the first two decades the rate of increase of output per employee-hour in the private economy averaged 3.2 percent per year; then, in 1967–77 that rate dropped by half, to 1.6 percent. The latter period did include the 1974–75 recession—the most serious of the postwar period—when production declined measurably. However, the Council of Economic Advisors and the Council on Wage and Price Stability have concluded that even when rates are corrected statistically for business cycle fluctuations, productivity growth rates for the past decade were significantly lower than they had been at any other time since the end of World War II.

Also, the slowdown was fairly widespread among industries. Approximately two thirds of the 62 industries for which the U.S. Bureau of Labor Statistics (BLS) reports data showed declines in rates of productivity growth during 1966–76. There was an absolute decline in productivity in mining of copper and coal, indicating increasing real costs (inflation corrected) of obtaining the raw materials essential to industrial progress. After two decades of rapid improvement averaging 6.8 percent a year, output per hour in coal mining during the last decade declined at a rate of 3.6 percent a year; copper mining declined at about 0.2 percent a year.

The story has been rather different in industries employing substantial numbers of electrical engineers. Output per employee-hour continued to rise at above-average rates in electric utilities, which averaged an annual increase of 3.6 percent over the 1966–76 decade. However, even this was down from the 7.2-percent annual rate for the 1947–66 period. Telephone communications recorded a 5.6-percent annual rate of increase from 1966–76; this compared with 7.2-percent growth over the 1951–66 period.

Perhaps the most often cited example of decreasing industrial productivity is provided by the plight of the U.S. steel industry. Improvement in output per hour has lagged, averaging only a 1.8-percent annual gain over the 1966–76 period, whereas European and Japanese competitors have improved productivity at a rate several times greater. By 1976, Japanese steel producers had actually exceeded the U.S. steel productivity level, and the competitive position of their U.S. counterpart has so deteriorated that Federal intervention has become necessary.

Even the fact that the U.S. is currently in a postrecession expansion does not alter the view of those experts who predict trouble ahead. As capacity utilization rates improve in the early stages of a business expansion, substantial advances in productivity can be expected. The rate of productivity growth then levels off in the later stages to the extent that the U.S. comes up against capacity constraints. So far, during this expansion, the early advances have taken place at a slower rate than during previous expansions. Further, the pro-

Edgar Weinberg
U.S. Department of Labor

ductivity increase during the current expansion has already tailed off markedly—only 2.4 percent in 1977 compared with a 4.2-percent increase in 1976.

Admittedly, it is difficult to project productivity in view of the multiplicity of factors that influence the trend—changes in production techniques, the volume of capital investment, the education and experience of the work force, the quality of management, the rate of capacity utilization, the scale of operations, the state of labor-management relations, and the impact of government regulation. The productivity of the economy is also affected by changes in the industrial composition of employment, such as the shift from the farm to the nonfarm sector. These factors are interdependent and the interaction among them is of considerable importance in the overall picture.

Still, as the experts point out, the long-term outlook for U.S. productivity is disquieting. The BLS, for example, projects a rate of 2.4 percent for 1980-85—higher than in the 1968-79 decade, but still significantly below the postwar, 20-year 3.2-percent trend. Other experts project an even lower productivity rate of 2.0 percent per year.

The productivity climate in Europe and Japan is not all rosy either, but while growth there has slowed of late, its pace is still faster than in the United States. Output per employee-hour in Japan, for example, is projected to grow at a rate of 6 percent a year, and worldwide communication and transportation, investment capital, advanced technology, and skillful management are so transferrable across borders that higher productivity is a realistic national goal throughout the industrial world.

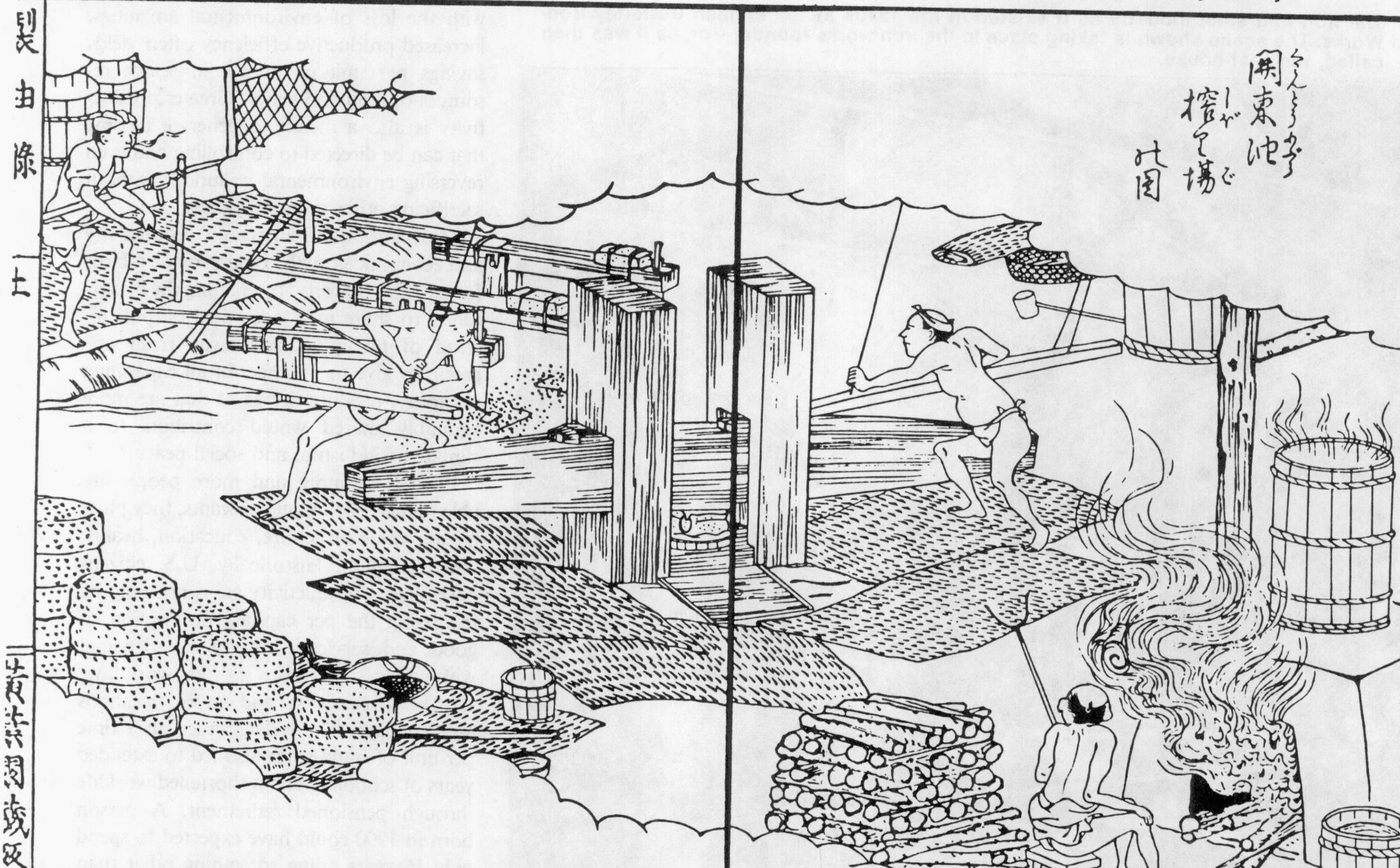
The measurable factors that contribute to the low U.S. growth rate in the past decade have been delineated by economists in great detail. They include the end of the shift from farm to nonfarm employment; the influx of a substantial number of inexperienced young people and women into the labor market; and the slowdown in the growth of the capital/labor ratio. The shift to business and personal services was *not* a major source of the slowdown. (Because adequate measures of government output are not available, the impact of the growth of this major service sector on the economy's performance cannot be fully assessed.)

On the other hand, the intangible influences of the economic and social setting on productivity are too often overlooked. The past decade was characterized by an unusual accumulation of disturbances. Not only were there exceptionally sharp fluctuations in output and employment, but shocks were produced by sharp rises in the price of energy, materials, and food. And the expansion of government regulation resulted in business uneasiness that, in turn, may have resulted in conservative management practices not conducive to continued high productivity.

Why productivity matters

One cause of the lack of concern over U.S. productivity performance is the failure of policy makers to appreciate fully the relationship of productivity to major national economic and social goals. Improved productive efficiency means better control of inflation, conservation of jobs, higher living standards, and a better quality of life in general.

The Japanese oil industry in 1836—not the petroleum industry; the extraction of oil from rapeseed. The productivity-spurring technology shown is from a book, *Seiyu Roku*, lent by Bern Dibner, director of the Burndy Library.



The experience of the early 1960s demonstrated the anti-inflationary implications of high productivity growth. Price stability was achieved in the first half of the 1960s because output per employee-hour gained at the substantial rate of 3.6 percent a year, which was about the same rate of increase as hourly compensation. In the period when real hourly compensation increased at a slightly slower rate than rising productivity, unemployment gradually fell below 5 percent.

During the past decade, however, hourly compensation increased at an average annual rate of 7.8 percent while output per hour rose, on the average, only 1.6 percent a year. The result has been a 6.1-percent annual increase in unit labor cost, and about a 5.9-percent rise in prices. Compounded over a decade, a 6-percent inflation rate reduces the purchasing power of fixed incomes by almost half.

Productivity affects jobs in another way. As the historically higher rate of productivity growth offset higher U.S. wage costs, U.S. industry's competitive position in expanding world markets was strengthened, conserving domestic jobs without resorting to restrictive trade policies. However, the more rapid increase in manufacturing productivity in Japan, Germany, and elsewhere has narrowed, and in some key industries (such as steel) eliminated the U.S. productivity advantage.

Between 1970 and 1975, other countries experienced more rapid increases in hourly compensation and unit labor cost than the U.S., which diminished the advantage of higher gains in productivity. But in 1976 and 1977, the increase in unit labor costs was slower in West Germany and Japan than in U.S. manufacturing. Currency devaluation and protectionist trade policies can serve only as short-term palliatives for overseas competition. Long-term stability and job conservation depend on improving the underlying productivity growth rate of U.S. industries. To the extent that U.S. firms increase their market by improving productivity, employment in the U.S. can be increased.

The third area directly affected by productivity is standard of living. The growth of productivity is a key factor in the long-term expansion of the economy, which, in turn, enables the U.S. to raise its average level of living. In the 30 years since 1947, the real output of the nation's private business increased two and a half times. Only a small fraction of the increase reflected an increased labor force. About three fourths of the rise was accounted for by increased productive efficiency of the work force. Moreover, it will be even more urgent to maintain a high rate of productivity growth over the coming decade if the economy is to expand at its historic potential growth rate of 4 percent per year. Since the potential work force is expected to increase at only about 1 percent a year—a reflection of the steady decline in U.S. birth rates since 1960—the potential growth of the economy could fall below its historic trend, unless output per hour increases at a rate close to 3 percent a year.

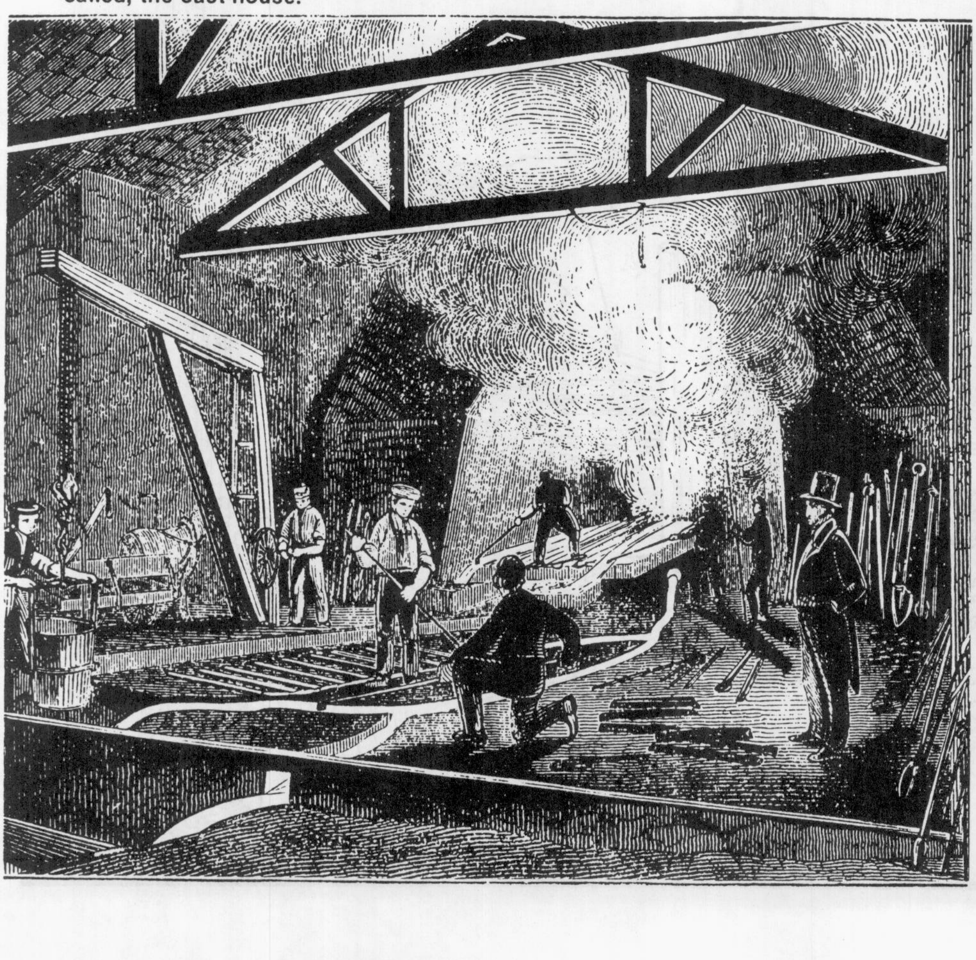
Productivity growth is even more important in accounting for the improvement in real output per person, a rough measure of the average level of living. Over the 30-year period, the hours worked per person in the U.S. declined. As a result, the entire growth in real output per person reflects the improvement in real output per hour—that is, productivity.

Economic growth has meant a better life, not only in terms of greater amounts of goods and services per person, but in their variety. And although such economic progress is sometimes associated by those critical of the consumer-oriented economy with the loss of environmental amenities, increased productive efficiency often yields savings per unit of output in scarce resources of land and water. Greater productivity is also a means to generate income that can be directed to controlling and even reversing environmental pollution, without sacrificing other economic goals.

Most important, increased productivity and economic growth could provide a basis for reducing poverty, by creating the opportunity to share in a larger real output, instead of taking income away from one group to give to another. In an expanding economy, productivity gains that are more equitably shared would contribute to a climate of industrial and social peace.

Finally, as more and more people are able to meet their material wants, they place greater value on leisure, education, health, and recreation. Historically, U.S. citizens have shared productivity gains not only by increasing the per capita consumption of good and services, but by experiencing, without loss of pay, shorter workdays, shorter workweeks, and more vacations and holidays. The reduction in labor time per unit of output has also led to extended years of schooling and a shortened worklife through pensioned retirement. A person born in 1900 could have expected to spend only 16 years doing something other than

The iron and steel industry as it existed in the 1840s at the English Butterley Iron-Works. The scene shown is taking place in the iron works foundry—or, as it was then called, the cast-house.



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work; for someone born in 1970, that period should increase to 27 years.

How to improve productivity

From the point of view of the National Center for Productivity and the Quality of Life, there are four broad areas for improving productivity: accelerating technological innovation; enlarging capital investment; enhancing human resources; and improving government-business relationships. In developing a perspective on major opportunities in these complex areas, the Center convened panels of experts from business, labor, and government, and commissioned studies to supplement existing research. The following highlights of this experience are presented not as a final consensus but rather as a summary of preliminary findings in a continuing search for possibilities for productivity improvement.

Productivity improvements come about through changes in production, methods, materials, and machinery, which, in turn, stem from the accumulation of scientific and technological knowledge. The technology factor is credited with at least 40 percent of the growth in productivity over the past 50 years.

Technological change has an impact on productivity at the time when a new technology is put into place and efficiencies are achieved. Before this can happen, an innovation must be conceived, information regarding it must be diffused to potential users, and the innovation must be implemented. Therefore, the entire process must be considered before productivity improvements can be realized.

We have no definitive indicators on whether the process of new developments has slowed recently, except in terms of one final result—the slowdown in productivity growth. In the opinion of the National Science Board and other authorities, the environment for innovation seems to be less favorable and the momentum of technological progress is waning. It would be useful to have comprehensive data on the speed of adoption of new technology, the time period between stages, and the comparative status of U.S. technology in relation to other countries in order to be able to gauge the pace of change. In the absence of such data, we must be willing to draw conclusions from a number of more indirect indicators.

One unfavorable trend is declining support by the U.S. Government and industry for research and development. Despite evidence of large private and social return from R&D, total spending for R&D by industry, government, and universities dropped from 3.0 percent of GNP in 1964 to 2.2 in 1977. The National Science Foundation expects the ratio to decline to 2.0 percent by 1985. Total R&D dollars spent increase each year, but when adjusted for inflation, the real volume of R&D spending has been declining.

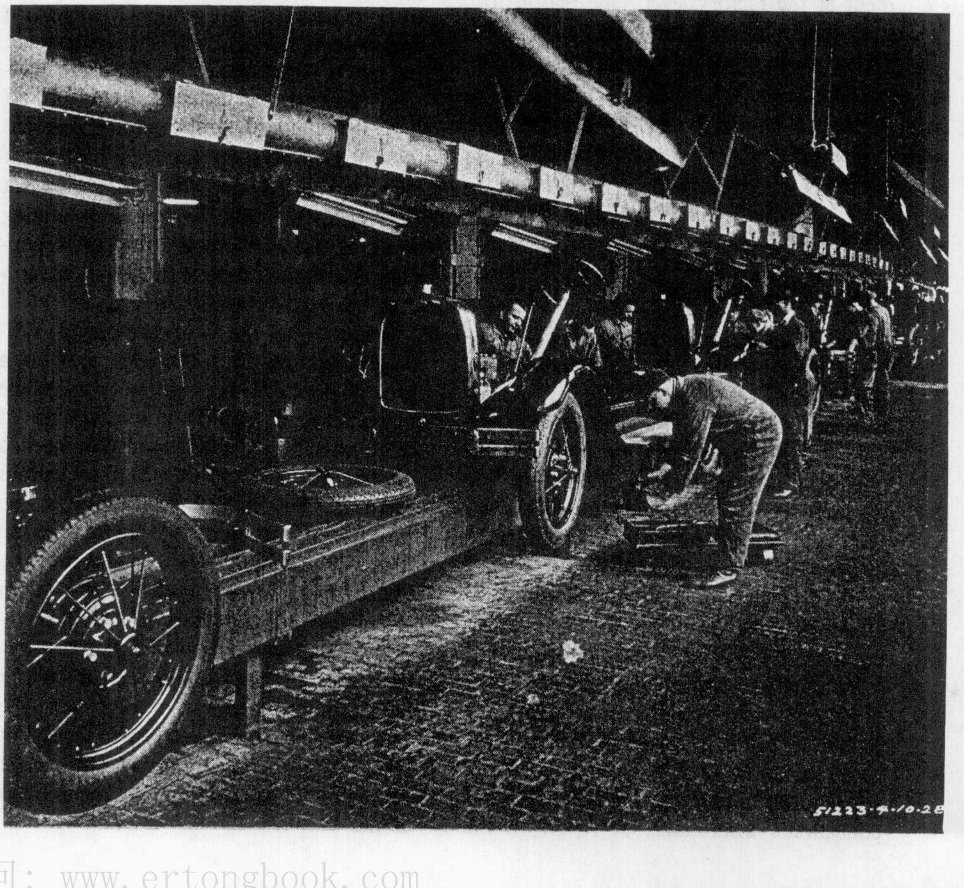
Comparative data for major industrial nations show a slippage in the U.S. position since the mid-1960s, relative to Japan and the U.S.S.R. These nations are devoting an increasing proportion of GNP to R&D. Patent activity by non-U.S. inventors is also rising; for example, 37 percent of all U.S. patents went to "foreigners" in 1976, compared with 17 percent in 1961. This increase in "foreign" patents is disquieting not because it is a reflection of a loss of creativity of U.S. scientists or the quality of their inventions or discoveries (which it is not), but rather because R&D outlays tend to have a positive correlation with productivity growth and a decline in the U.S. proportion of patents could foreshadow a slowdown in the flow of new products and processes.

The lack of adequate support for research and development of manufacturing technologies is especially disturbing. For example, experts have reported that the U.S. trails West Germany in R&D in metalworking (an area that is vital to productivity improvement). The Japanese Government is giving full support to R&D on automation (flexible manufacturing systems). The only reasonable conclusion from all this is that the U.S. no longer has sole control of technical leadership in manufacturing technology developments.

The reasons for this slowdown are difficult to determine. Economists often treat technological innovation as exogenous and subject to its own laws of development. At a recent conference on the future of productivity, Simon Ramo stated, "The bottleneck is not science and technology *per se*, but lies instead in the arrangement-making process among government, private enterprise, and science and technology." Thus, the pace of innovation is affected by many nontechnical factors, including the state of the economy; the profitability of investment; the patent, tax, antitrust, and regulatory policies; the structure of industry; the skill and knowledge of management and the work force; and the pressures of organized interests.

Resolving the bottleneck involves closer cooperation among the different groups in the process—scientists, engineers, inventors, manufacturers, distributors, users, consultants, and others. The groups in this complex chain pursue different and sometimes conflicting goals, are motivated by

The assembly line—that famous productivity innovation—is shown here as it existed in 1928 in the Ford motor works. Photo from the Henry Ford Museum, Dearborn, Mich.



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