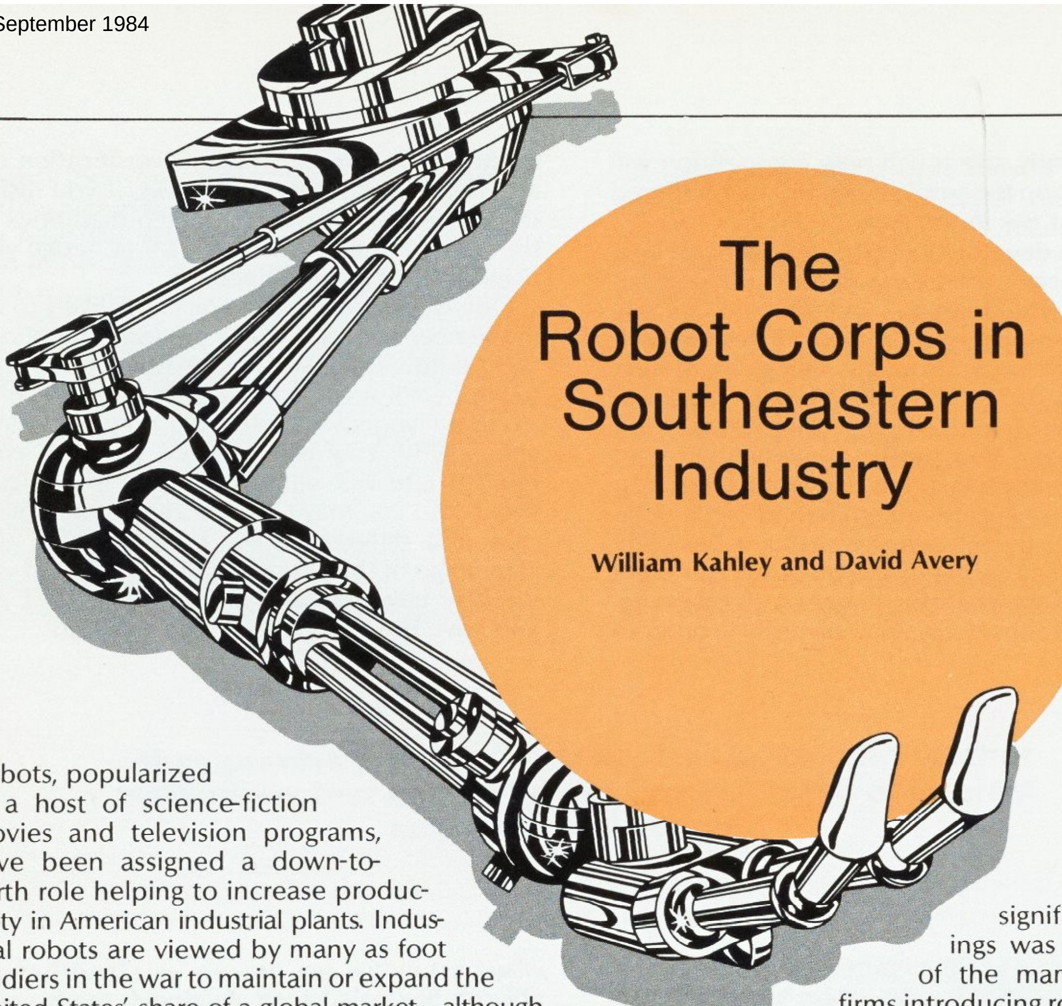

The Robot Corps in Southeastern Industry

William Kahley and David Avery

Robots, popularized in a host of science-fiction movies and television programs, have been assigned a down-to-earth role helping to increase productivity in American industrial plants. Industrial robots are viewed by many as foot soldiers in the war to maintain or expand the United States' share of a global market—although to date robots represent only a small army. Just what is their potential value to U.S. industry in an international marketplace where such competitors as Japan frequently seem to outperform our own manufacturers?

The Federal Reserve Bank of Atlanta decided to look at the current and expected future use of robots in the American workplace, particularly in the Southeast. Information on the use of robots in southeastern industry has been scarce and we believed that, by surveying users and potential users of industrial robots, we could contribute to the region's knowledge.

Our survey drew a response that was both helpful and at times surprising. One of the most significant findings was that most of the manufacturing firms introducing robots were influenced primarily by the need to reduce labor costs. That seems logical in view of the increasing competition American manufacturers face from low-cost foreign producers of goods ranging from steel and automobiles to textiles and apparel. Industry analysts have been in general agreement that U.S. producers must reduce the labor content of their domestic products. Otherwise, the stiff hand of competition might close markets to our producers permanently or force them to manufacture their goods offshore, relying on less-expensive foreign labor.

The predicament of U.S. manufacturers confronting low-wage foreign competition has been summed up by financial writers in the phrase, "emigrate, automate, or evaporate." Some U.S. manufacturers have chosen to pursue automation aggressively, turning to high-technology improvements such as robotics to produce traditional

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While androids such as R2D2 and C3PO still may be light years away, many U.S. industries already rely on robots to perform difficult or dangerous jobs. Atlanta Fed economists recently conducted a survey to learn how robots are helping America regain a competitive edge in critical industries.

"smokestack" goods in this country at lower cost. Robots are only one element in the array of high-tech improvements being adopted by various industries (see Box 1). Yet the expansion of robotics has been handicapped by several limitations involving both systems and personnel. Judging from our research, U.S. manufacturers need more experience with robotics systems as well as additional technological breakthroughs if the number of robots in operation is to expand as rapidly by the end of this century as some optimistic forecasters expect.

What is the future of robots in the American workplace? How great a role will they play in southeastern industry, and how important are they to manufacturers in the region today? To what extent are robots likely to displace human workers? Responses to these and related questions could, we believe, help us to understand the probable development of the southeastern manufacturing economy. We hope that our survey contributed some of the answers.

What Is a Robot?

R2D2 and C3PO, imaginary androids from the popular *Star Wars* movies, have little in common with the approximately 7,500 industrial robots in use in U.S. manufacturing plants today.[1] (Some firms, however, are producing and developing robots that serve drinks, clean carpets, defuse bombs, patrol for security, and entertain.) According to the Robotic Industries Association, formerly the Robot Institute of America, a robot is any "reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks."[2] The key terms here are "reprogrammable multifunctional manipulator" and "variety of tasks;" in other words, robots are machines that can use tools to perform different jobs when they are told to do so. An advanced robot typically is composed of the following parts:

—hand, gripper, or sensing device (such as vision or touch)
—an arm or manipulator mounted or supported on a base
—a control computer and software
—a power supply.

The basic process is that the controller tells the arm and hand (or tool) what to do and they perform the task with energy obtained from the power source.

Where Are the Robots?

The first industrial robots were introduced in the United States nearly 25 years ago, but as late as 1972 worldwide sales were only $6 million. Since then sales have climbed more rapidly, reaching $190 million in the United States alone in 1982, or $112 million in 1972 dollars.[3] Historically there has been a 12-to 15-year time lag between the development of a technology and its adoption in the workplace. So far, the case of robots has followed this pattern.[4]

About 50,000 robots were in use worldwide in 1982.[5] Of these, nearly two-thirds were in Japanese establishments, compared with 14 percent in the United States and 7 percent in West Germany. About 60 domestic companies produced and distributed an estimated 2,500 robots in 1983.[6] Another 140 foreign producers sold about 1,000 robots in the U.S. market in 1983.

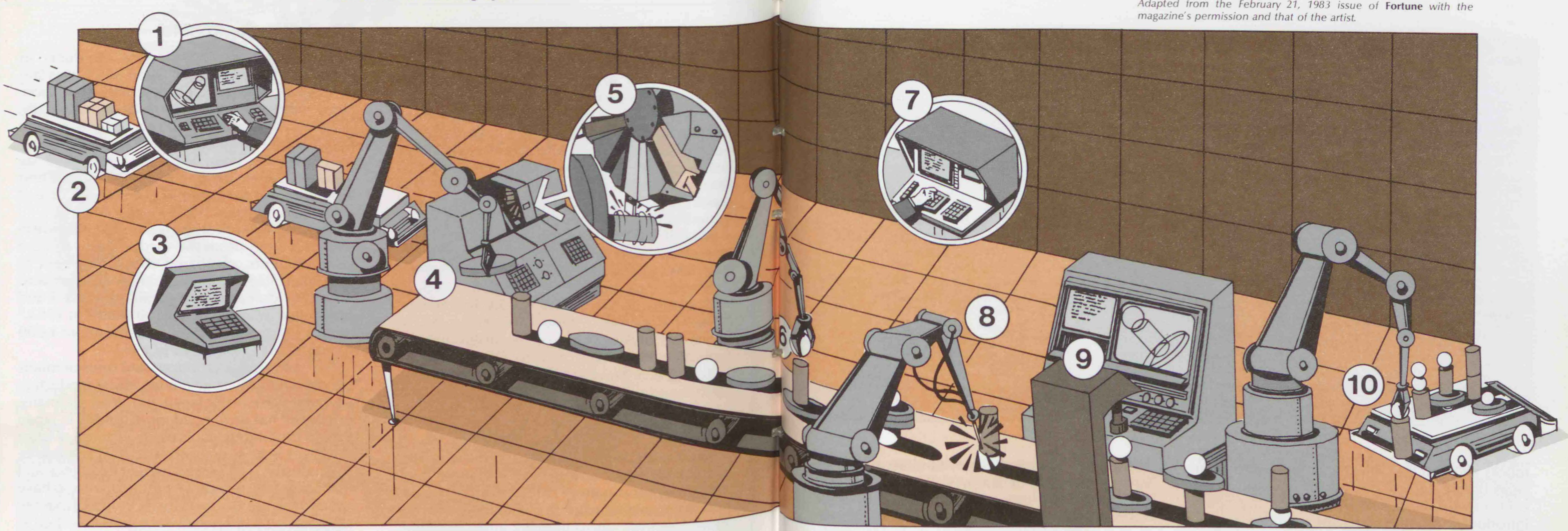
The main foreign producers and users of robots are countries with large motor vehicle production facilities, particularly Japan and West Germany. Robot use has developed more quickly in Japan than in the United States partly because of labor shortages in its strong and fast-growing automobile industry. Japan's government assistance and managements' receptive attitude may also have spurred the use of robots there. In 1982 Japanese sales totaled $480 million for robots classified as such in the United States. West Germany's robot production in that year amounted to $108 million, and other Western European countries lagged substantially behind.

The automobile industry is the largest user of robots in this country as well, accounting for 50-60 percent of the installed robot population. Within the auto industry the dominant applications are for painting, welding, and material handling—the "dull, dirty, dangerous" or "hot, heavy, hazardous" tasks that highlight robots' advantages in the workplace. In other industries that are relatively heavy users of robots, such as the aircraft, appliance, and foundry industries, robots are used for machining, molding, machine loading or unloading, general material handling, and in many assembly operations.

It should be noted that robots vary widely in structure, sophistication, and cost. With a median price of about $60,000, the robot itself ordinarily represents only about one-quarter of its total installation cost. Most robots are not energy intensive, relying on small electric motors or hydraulic systems for movement. In general,

Flexible Manufacturing Systems

*Adapted from the February 21, 1983 issue of **Fortune** with the magazine's permission and that of the artist.*



1 An unprecedented diversity of operations can be performed by a fully automated flexible manufacturing facility. Work begins with product design on a computer-aided system, an electronic drafting board that conveys information to the central system.

2 Directed by the computer, a parts carrier brings raw materials to the line. Loaded automatically at the storage area, carriers usually are guided by low-frequency radio signals transmitted through a wire buried in the floor.

3 Remote terminals allow management to keep track of the activity on the unmanned manufacturing line. Without leaving his office a manager can ask the robots what they have done for him today—say, how many products they have turned out.

4 A robot unloads raw metal blanks from the carrier cart, places them in a lathe, and then transfers the finished part onto the conveyor. The "pick and place" robots are programmed for their tasks, but new ones under development will be guided by vision or touch.

5 A revolving holder supplies the appropriate tools for each part to be machined. Directed by the central controller, the lathe automatically picks the right tool and performs the prescribed cutting operations.

6 Continuing the programmed sequence of operations, an assembly robot puts the parts together. Assembly robots are just beginning to come into their own. The joining of complex parts is more difficult to automate than machining.

7 An electronic foreman—a computer terminal known as a programmable controller—directs the work. Reprogrammed at its keyboard by a human supervisor, the controller can change the number and type of products being made.

8 A welding robot joins the parts, making as many welds as necessary on all sides. Until the advent of flexible automation, such robots usually were stand-alone, single-purpose units installed as replacements for human welders.

9 The newly made product is scrutinized by a camera containing a semiconductor chip that can "see" and instantly measure deviations from standards. Automatic inspection is an area where U.S. manufacturers excel.

10 A robot places each product in precisely the right spot on an automatic cart that will carry it off to a shipping area. Should something go wrong, red lights will alert human "tenders" who walk through the plant monitoring production.

The president of an Atlanta-based company that specializes in designing and fabricating turnkey systems utilizing industrial robots likens robots to a screwdriver in a mechanic's tool box. "A well-equipped tool box will certainly include a screwdriver, but a tool box full of nothing but screwdrivers is of limited use. That's the way it is with a robot. It's a tool—one of several in a well-designed flexible manufacturing system."

Flexible manufacturing systems (FMS) integrate the use of computers, robots, machine tools, and automated material and parts handling. Their key feature is that they can readily adapt to change. FMS can be programmed to produce several parts simultaneously and be quickly reprogrammed to incorporate product design changes or to produce new parts. By contrast, traditional "fixed automation systems" follow a prescribed manufacturing sequence designed to churn out identical products in huge volume. Retooling fixed automation systems to produce new or improved items tends to be a long and costly process.

The economic significance of FMS is linked to its advantage over the fixed system in producing manufactured goods in small batches, which are the bulk of manufacturing applications.[7] Whereas FMS can realize scale economies over a wide range, Detroit-style fixed systems achieve their greatest economies only when they mass-produce products and components such as automobiles and tires. Enthusiasts of the futuristic factories even imagine producing custom-designed goods for individual buyers as efficiently as the fixed systems produce a million identical items. As an additional advantage, flexible systems enable manufacturers to respond more quickly to changes in market demand, creating attractive opportunities for manufacturers who can adjust, but serious problems for rivals who fail to employ flexible systems.[8]

How do flexible systems boost productivity to achieve cost savings? Because manufacturing is fully automated, there are reductions in setup and retooling costs, in time delays in the production process, and in material waste caused by human errors. Equipment utilization is thus increased, labor and materials are used more effectively, inventory is lessened, and product quality attains greater consistency.[9]

Systems such as the one described above are not yet fully operational anywhere. But some companies, particularly in Japan, are clearly moving toward the workerless factory. In the United States only about 30 flexible systems are currently operating, with a market value of $250 million. But the U.S. Department of Commerce expects the entire factory automation market to grow to $15 billion by 1988.[10] Increased foreign competition makes the overall sharp upward trend to automation inevitable. Indeed, the future survival of many U.S. firms demands it.

Table 1. Number of Robots by Industry and State
(survey data, April 1984)

Industry	Ala.	Fla.	Ga.	La.	Miss.	N.C.	S.C.	Tenn.	Multi-state	Region	Percent of Total
Furniture/Fixtures					1			4		5	0.3
Chemicals						1	4			5	0.3
Rubber			7							7	0.6
Stone/Clay/Glass								28	1	29	2.3
Primary and Fabricated Metals	24	1	4	4	3	20	2	48	4	110	8.8
Machinery, except Electrical		6				1			20	27	2.2
Electrical/Electronic Machinery	10	115	18	3		80	8	14	60	308	24.6
Transportation Equipment	32	13	60	32		44	7	313	20	521	41.6
Instruments		4				3		10		17	1.4
Miscellaneous Manufacturing	6	35	6			25		31		103	8.2
Educational Services				3		11	2		2	18	1.4
Services			1					11		12	1.0
Other	30	15	13			23	1	9		91	7.3
State/Regional Total	102	189	109	42	4	208	24	468	107	1,253	–

Source: Federal Reserve Bank of Atlanta, April 1984.

robots will function effectively for five to eight years before a major overhaul is required; however, newer, more effective models are being introduced monthly into the marketplace as alternatives to robots already in use.

According to the Bureau of Labor Statistics, "some lesser skilled production occupations (such as operatives) are threatened by the introduction of robots and other automated equipment. But their current introduction is hampered by factors such as the lack of visual capabilities and by their purchase, installation, and maintenance costs.... If the robots' capabilities can be improved and their associated costs can be reduced through mass production, we may see an occupational impact."[11] In spite of current constraints, industrial robots are projected to reduce the growth in employment of welders, production painters, and material-moving occupations. Enlightened managers can ease the transition for these workers through education and retraining.

Robots in the Southeast

Little detailed information is available concerning the use of robots outside the automobile industry, and data on the use of robots in the Southeast are even more scarce. To find out more about robot use in this region, we surveyed subscribers to the Society of Manufacturing Engineers' magazine of automated manufacturing, *Robotics Today*, in Sixth District states plus the Carolinas. The 325 respondents to our April survey questionnaire constitute 22 percent of the subscribers in the Southeast. Their responses provide useful and sometimes surprising information concerning the region's robot profile.

The total number of robots used by responding southeastern firms is 1,253, a conservative estimate of the total robot population in the region and about in line with the national total considering the industry mix.[12] The eight states in the region account for about 18 percent of the country's manufacturing employment, the sector associated with using robots. If manufacturing industries nationally used robots in the same proportion as our survey indicates they are used in the Southeast, an estimated one per 2,711 workers, the U.S. robot population would total nearly 7,100. The actual U.S. International Trade Commission estimate of the robot population nationwide in 1982 was 7,200.

The distribution of robots by industry reflects their advantages in particular applications. Most robots used in the Southeast are found in the transportation equipment, electrical and electronic machinery, and fabricated metals industries (Table 1). They are used principally for

Robotics in the Textile Industry

The textile industry is the largest manufacturing employer in Georgia and the Carolinas. Numerous small communities in these and other states in the region are economically dependent on payrolls generated by textile and apparel firms. New investments to increase productivity, efficiency, and profitability in this mature industry are being made in an attempt to survive intense foreign competition. In 1983 the industry spent $1.3 billion in its revitalization effort, mostly to purchase automated and computerized equipment. The industrial robot is one of the new tools that has been brought into the textile mill.

Most robots in textile mills are used to handle material. Robots' flexibility enables them to stack and pack heavy yarn spools in different locations and patterns—a job that can be highly inefficient and dangerous when performed by factory workers. It is also a dull and tedious job.

Special technical problems inhibit the use of robots in the textile industry. Textile mills tend to be old facilities with narrow aisles between the machines, which makes it difficult to employ robots that require more space. The "pliant nature" of textiles and the numerous product inspections at various intermediate stages of production require robots with relatively sophisticated touch-and-sight capabilities. Forward-thinking managers must design plants with an eye for automation, leaving enough room for the robot to function at various work stations. Furthermore, new technologies that equip robots with vision systems for product inspection and grippers for easy manipulation of textiles will be required.

These "problems" probably will be solved in the not-too-distant future, according to experts.[13] For now, textile facilities such as American Enka's Clemson, South Carolina plant and Burlington Industries' Erwin, North Carolina plant use robots principally as part of a sophisticated material handling system. Other applications in the industry are sure to emerge as producers find ways to tap the productivity enhancing potential of robotics.

welding and painting operations; materials handling, including loading and unloading of machine tools and molds; and in assembling of products, such as printed circuit boards and other industrial and consumer goods.

Within the region, the use of robots by state may seem somewhat surprising (Table 2). Tennessee and Florida account for a relatively large share of the robot population compared with these states' manufacturing employment. The concentration of robots in Florida reflects, in part, its status as a fast-growing center of high-technology employment. The state is home to major robot manufacturer-users such as IBM, and is a center for the mushrooming electric and electronic machinery industry, which increasingly uses robots in assembly.

The manufacturing sector's share of nonfarm employment in Tennessee is higher than in any other regional state except North Carolina. Tennessee's manufacturing employment is concentrated in auto and housing-related durable goods industries, which use robots heavily. Nissan's truck assembly plant in Smyrna alone uses 240 robots. Auto assembly likewise accounts for much of Georgia's robot use: GM and Ford employ dozens of robots to assemble cars in Atlanta. In Alabama, where robot use is about proportionate to the state's share of the regional blue-collar work force, robots are used in smokestack industries, chiefly primary and fabricated metals, transportation equipment, and aerospace and defense.

North Carolina's firms account for a large portion of the region's robot population, but not in proportion to its share of regional manufacturing employment. Manufacturing employment in the state is largely concentrated in textiles, an industry that has difficulty adapting mills for robot use (see Box 2). The use of robots per manufacturing employee is similarly constrained in Georgia, South Carolina and, to a lesser extent, Alabama.

Louisiana and Mississippi apparently use few robots. In Louisiana, manufacturing is heavily concentrated in industries related to oil and gas extraction and petrochemicals. Robot applications in these capital-intensive industries are extremely limited compared with manufacturing industries that employ many blue-collar production-line workers. In Mississippi, where the work force is largely non-unionized, labor is still relatively abundant at moderate cost.

Differences in the characteristics of robot-using and non-using firms in our survey are revealing. Roughly 60 percent of those responding to our survey were robot users. Across the region, firms that use robots tend to be large,

Table 2. Number of Robots and Shares of Southeast's Robots and Manufacturing Employment, by State (survey data, April 1984)

State	Number of Robots	Share of Robots	Share of Manufacturing Employment
Alabama	102	8.1	10.2
Florida	189	15.1	14.2
Georgia	109	8.7	15.4
Louisiana	42	3.4	5.3
Mississippi	4	0.3	6.2
North Carolina	208	16.6	23.4
South Carolina	24	1.9	10.9
Tennessee	468	37.4	14.4
Multi-state*	107	8.5	–
Southeast Total	1,253	100.0	100.0

*Multi-state refers to respondent reports covering aggregate robot use in more than one state in the region. The distribution of these robots by state cannot be determined, but the distribution of the respondents' mailing addresses is similar to the distribution of robots by state.

Source: Federal Reserve Bank of Atlanta, April 1984.

with two-thirds of the plants employing over 500 workers. Extremely large plants, those with more than 2,500 workers, account for 30 percent of the region's users. Among users, well-established firms predominate: two-fifths of the users in our survey were founded before World War II. By contrast, one-fourth of the non-users employ fewer than 50 workers and only one-third were founded before the war.

The robot user profile, by firm size and age as well as by type of industry and robot application, suggests that enhancing productivity is crucial to the manufacture of new and mature products. But information from our survey of user-respondents suggests that using robots is a recent development to improve productivity. Over 50 percent of the users adopted robots within the past three years.

Why Use Robots?

The demand for robots is linked to the productivity gains they bring to the workplace that reduce costs and improve quality. In addition, robots can enhance workers' safety and tighten control over the entire manufacturing process. All of these benefits add to the "bottom-line" incentives for employing robots.

The particularly widespread use of robots in automobile production is attributable to their clear technological, economic, and environmental advantages. In welding, painting, and gluing applications, robots' precision lowers production costs by conserving materials. Where they take over dangerous jobs, robots reduce worker injuries and accompanying compensation claims. Robots can also work in unhealthy environments that otherwise would require expensive equipment to comply with environmental regulations for worker protection.

Product quality often improves with the use of robots in manufacturing. Welds, for example, can be made more precisely and with greater consistency when a robot replaces a worker, who is subject to fatigue and boredom. The improved quality of welding translates into increased profitability through reduced scrap and in-process inventory (because less reworking is required), and fewer returned goods and service calls.

Saving on direct labor costs has been a crucial incentive for robot use in the U.S. automotive sector, where workers are the highest paid in the industry worldwide.[14] To regain competitiveness with foreign car manufacturers, U.S. companies have bought robots whose cost per hour, including depreciation, maintenance, and capital charges is only one-fourth the approximately $23-an-hour compensation for labor.

Robots bring other benefits to machine-tooling processes. For example, robots can perform deburring, grinding, and routing operations without using templates, thereby lowering production costs. In hot and heavy jobs, like foundry work, robots save time and money by reducing material transfer and work environment costs. In these and other industries, robots can increase the utilization of other capital equipment employed in the manufacturing process.

The flexibility that robots permit is a major benefit to producers. With reprogrammable robots, a single system can replace several production lines for multi-product small batch and mixed-flow-line production and this saves on capital equipment and plant size. Enhanced production-control flexibility and quick feedback also allow rapid adjustments that improve quality and reduce waste and inventory. The reprogrammability feature of robots is especially helpful in shortening producers' response time as market demand develops for new products.

We asked robot users in the Southeast to rank, in order of importance, the reasons they first introduced robots into their plants. Fifty-five percent indicated that they aimed primarily to reduce costs, 16 percent wanted to increase their output, 10 percent hoped to improve product quality, and 8 percent wanted to eliminate dangerous jobs. Their results seem encouraging. Only 2 percent of the user-respondents reported that robots failed to help them achieve their objectives.

Why Aren't More Robots Used?

Available figures for the actual number of robots produced and sold by American robot manufacturers are imprecise. But sales in recent years clearly have lagged behind the expectations of many forecasters. Some of the slower-than-expected growth may be attributable to the economic recession nationally, but other forces also are limiting growth.

Leaders in the robotics industry say managers of many U.S. companies remain unaware of what robots and automated systems can do for them. Their observation is consistent with general studies concerning the diffusion of technology. Robot use is still in its infancy, and a major requirement for faster growth is more widespread information and awareness about robots.

Today's early developmental stages of robot technology may also be impeding use. Current robot vision and touch capabilities are limited; in fact, fewer than 10 percent of today's robots possess any vision at all. Research is underway into basic components such as sensors, control systems, and computer program languages to accelerate growth in robot use. Another possible factor inhibiting growth may be a shortage of engineers and other technicians who are expert in the application of robots in a total manufacturing system.

The economics of introducing a robot into the workplace has an obvious limiting effect on the spread of robots in manufacturing. To optimize robot capabilities, work spaces often have to be rearranged and other machinery or parts redesigned. Typically, total installation costs run from 150 to 500 percent of the initial cost of the robot, which ranges from $45,000 to $240,000 depending on sophistication.

Robot usage also has been constrained by the complexity of robot systems and by sunken costs in existing plants and equipment. Furthermore some critics of U.S. management argue that an overemphasis on short-term profitability derails many robot projects and that the scarcity of needed information makes managers cautious about investing in robots. For example, it is often difficult to estimate in advance the cost of software required to integrate a robot into a particular plant's operation. Consequently, companies are more inclined to approve capital projects that replace conventional tools with improved models than more efficient but dramatically innovative manufacturing processes that use robots.

Some industry observers claim that actual and potential opposition from blue-collar workers is another factor curbing the adoption of industrial robots. A number of union contracts include provisions that restrict or impede the introduction of new technologies into the workplace. But there is evidence that management can introduce robots successfully when workers are involved in the process and informed about job security and pay issues.[15]

Respondents to our survey cited cost considerations and technology unsuitable for their operations as the primary factors inhibiting robot use in the region. Nearly three-quarters of the non-users, however, expect eventually to use robots in their firms. Almost half of the non-users anticipate robot use before 1990. Two promising areas for growth are materials handling, including loading and unloading operations, and assembly. Potential users in our survey listed these categories as the most likely robotic applications. Most of the non-users who expect to use robots in the future operate plants in the oldest age category (1940s and before), mostly with 100 to 1,000 employees. Only among the smallest of firms (less than 50 employees) did a majority respond that they are unlikely ever to use robots.

What's Ahead for the Robot Industry?

Projections concerning the number of industrial robots that will be used in this country by 1990 vary widely; estimates for later years vary even more. The Bureau of Labor Statistics, in its most recent projections, estimates that 100,000 robots will be used in 1995. But some experts in the robotics area forecast dramatically higher robot usage, ranging up to 2 million by the end of this century.

The divided opinion about future robot usage is reflected in our survey responses. One-fourth of the participants declined to respond to our question about the expected robot population in 1995. The second most frequent response, by 16 percent of the participants, predicted a robot population of between 50,000 and 100,000 in 1995; however, 15 percent of the participants forecast 500,000 or more robots by that year. Firms that already have robots in place seem to be more certain and optimistic concerning the growth of robot use. Relatively more users responded to our question about future robot use, and they tended to expect a larger robot population in 1995.

Despite the lack of a consensus regarding the future number of robots, general agreement exists that robot use will grow rapidly. Nearly all forecasters expect an annual compound growth rate in the 25-35 percent range in the remaining years of this decade. Even from a low base, this fast growth would develop robot production into a $2 billion industry by 1990. Robot sales totaled $220 million in 1982 and the Bureau of Industrial Economics expects sales to rise to $265 million this year.

The speed and extent of diffusion of robots in the workplace depends on a complex of changes in future market prices for final products and in the resources used to produce them. From a technical perspective, robots can already perform numerous tasks in most industries. But individual companies will decide whether to adopt robots based on a comparison of the relative costs of labor and robots.

The difficulty of foreseeing developments in product and resource markets and their combined impact on the robotics industry limits our vision of the future use of robots. A chicken-and-egg type problem further clouds the future: buyers will not invest in robots until there is reliable equipment and programming, and manufacturers are reluctant to develop low-cost hardware and complete programming until there are enough buyers.

Seen from a historical perspective, opportunities always exist for the innovative and creative use of new and existing technologies. Even without an extensive search for new applications, many companies could employ robots profitably. Applications are most likely in plants where machines are underutilized, the amount of work in progress is high, workers toil in an unhealthy environment, and quality is uneven or poor.

Robot producers are faced with numerous opportunities for marketing their products more effectively. Some industry analysts say robot manufacturers could expand sales rapidly if they would standardize products and terminology to reduce buyer confusion, and if they would target sales presentations to a prospective customer's executive management rather than to engineers and plant managers. In short, they say, robot manufacturers should employ marketing techniques common in the computer industry, selling systems and solutions rather than hardware.[16]

Robots of the future undoubtedly will become more intelligent, flexible, and inexpensive. Improved software that integrates computer-aided development and manufacturing of products will facilitate robot producers' market expansion. Better vision and touch sensors also will help markets grow, and will greatly improve the value of robots for product assembly, in particular.

Our survey supports the optimistic view that adequate training programs will be available to prepare workers to program, operate, and maintain industrial robots in the next ten years. Nearly three-fourths of our respondents expect that robotic training programs will meet the needs of industry. According to Robotics International, 27 domestic institutions of higher education listed robotics degrees or options in their programs as of mid-1982, and 74 more offered robotics courses. However, formal education and industry instruction will have to meet an escalating demand as technological advances (such as vision and touch) are applied more widely.

Conclusions

Industrial robot use is likely to grow rapidly in the years ahead, benefiting individual workers and firms and the entire economy. Workers' standards of living should be boosted by the productivity gains that robots bring to the workplace, and they will profit from the elimination of dull, dirty, and dangerous jobs. By increasing productivity, robots may enable U.S. manufacturers to compete better with low-cost foreign producers, and might help make the national economy less inflation-prone. A reduction in the inventory required in manufacturing might even lessen cyclical fluctuations in GNP by dampening inventory swings.

But these gains will not be costless. The elimination of unskilled and semi-skilled jobs will impose adjustment burdens on displaced workers. Some business firms that are too slow to adopt robots will find their markets dwindling and may be forced to close their doors. Local and national policymakers are likely to come under increased pressures to develop programs to help these workers and firms adjust.

(Special thanks to Lester Ottinger and Harlan Grasier of Robot Systems, Inc., Richard Standring of the Society of Manufacturing Engineers, and Lori Manion of the Federal Reserve Bank of Atlanta.)

NOTES

[1]The word robot comes from the Czech word "robota," meaning servitude or drudgery. It came into the English language in the early 1920s via Karel Capek's play *Rossum's Universal Robots*.

[2]The name change reflects the association's desire to represent a broader base of robotic technology, including robot mobility, automation systems, and sensors.

[3]Estimate from U.S. Department of Commerce, Bureau of Industrial Economics, *U.S. Industrial Outlook, 1984*.

[4]Experts agree that the number of robots used in industry is likely to grow well into the 21st century. For example, representatives of the National Aeronautics and Space Administration and National Bureau of Standards have testified before Congress that robot technology is only in its infancy: "... this technology will probably not mature for 50 or 100 or maybe 200 years and ... these effects, dramatic though they may be in the next 10 or 20 years, will continue throughout the next century." (Testimony by Dr. James S. Albus, *Robotics Hearings*, Committee on Science and Technology, June 23, 1982.) Joseph F. Engelberger, the "father of robotics," thinks that "it's still an embryo industry." (See the Conference Board magazine *Across the Board*, June 1984, p. 22.)

[5]Data in this section are from U.S. International Trade Commission, *Competitive Position of U.S. Producers of Robotics in Domestic and World Markets*, USITC Publication 1475, December 1983.

[6]The Southeast is headquarters for a few major domestic producers. All of IBM's robot manufacturing and sales operations are located in Boca Raton, Florida, and General Electric's robotics systems service center is in Orlando. Cincinnati Milacron, another major domestic robot producer, makes robots in Greenwood, South Carolina.

[7]Office of Technology Assessment, *Automation and the Workplace* (March 1983.)

[8]See Gene Bylinsky, "The Race to the Automated Factory," *Fortune*, February 21, 1983, for a good nontechnical discussion of FMS.

[9]The initial investment for fully integrated systems, however, is often greater that that for fixed automation systems. See J. D. Goldhas and M. Jelinek, "Plan for Economies of Scope," *Harvard Business Review*, 61 (November/December 1983), for a discussion of the managerial opportunities and problems posed by FMS's.

[10]*U.S. Industrial Outlook, 1984*.

[11]G. T. Silvestri et al., "Occupational Employment Projections Through 1995," *Monthly Labor Review*, vol. 106 (November 1983), p. 97.

[12]There are two principal sources of measurement error in this estimate of the total robot population in the region. First, the actual number of robots is underestimated to the extent that some robot-using firms did not respond to our survey. However, we believe that our count of the number of robots for extensive users is virtually a population count for major users, and that the number of robots used by other non-responding firms is unlikely to be more than 5-10 percent of the total estimate we report. Second, our estimate overstates the number of robots to the extent that respondents reported their robot use on the basis of the broader Japan Industrial Robot Association definition of industrial robots. (The Japanese definition includes as robots some machines that are operated manually by a worker as well as "robots" such as machine tools or a drill punch or press whose time sequences of positions and operations are predetermined and almost fixed.) This source of measurement error should be small since all of the respondents to our survey subscribe to RIA trade publications and thus can be expected to use RIA's definition of a robot.

[13]See D. Underwood, "Robotics in Textiles," *Textile Industries*, 148 (March 1984).

[14]The cost of labor is a main component of the cost of manufactured goods. Thus, unit labor costs (which reflect changes both in worker productivity and compensation) play a major role along with currency exchange rates in determining relative prices for identical goods produced in different countries for sale in world markets. Expressed in U.S. dollars, unit labor cost for U.S. workers was comparatively low in the late 1970s as a result of the weak foreign exchange value of the dollar and faster growing wages for foreign workers. However, the relative cost of U.S. labor has increased in recent years as the dollar has strengthened against other currencies.

[15]See L. Argote and others, "The Human Side of Robotics: How Workers React to a Robot," *Sloan Management Review*, 24 (Spring 1983), and F. K. Foulkes and J. L. Hirsch, "People Make Robots Work," *Harvard Business Review*, 62 (January-February 1984).

[16]See W. J. Finch, "Why Aren't U.S. Manufacturers Using Robots?" *Robotics World*, 1 (December 1983).