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S. Hrg. 98-131

THE IMPACT OF ROBOTICS ON EMPLOYMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON ECONOMIC GOALS AND INTERGOVERNMENTAL POLICY

OF THE

JOINT ECONOMIC COMMITTEE CONGRESS OF THE UNITED STATES

NINETY-EIGHTH CONGRESS

FIRST SESSION

MARCH 18, 1983

Printed for the use of the Joint Economic Committee

U.S. GOVERNMENT PRINTING OFFICE
21-160 O WASHINGTON : 1983

1P11

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THE IMPACT OF ROBOTICS ON EMPLOYMENT

FRIDAY, MARCH 18, 1983

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON ECONOMIC GOALS
AND INTERGOVERNMENTAL POLICY
OF THE JOINT ECONOMIC COMMITTEE,
Washington, D.C.

The subcommittee met, pursuant to notice, at 10 a.m., in room 628, Dirksen Senate Office Building, Hon. Lloyd Bentsen (vice chairman of the subcommittee) presiding.

Present: Senator Bentsen.

Also present: Robert Premus and George R. Tyler, professional staff members.

OPENING STATEMENT OF SENATOR BENTSEN, VICE CHAIRMAN

Senator BENTSEN. Mr. Andelin, if you would come up and be seated.

This is a factfinding hearing to evaluate the prospective impact of robotics on employment in this country. Robotics refers to the use of sophisticated programable or computer-controlled robots to perform routine and repetitious tasks.

The use of robots has soared across our Nation and the world by firms that are under pressure to raise productivity and to reduce unit-labor costs. While we heard a lot of speculation as early as 1961 about robots, sales really only began to take off in 1979. There are now some 22,000 sophisticated robots in use worldwide. That includes about 5,000 in the United States. But sales are predicted to rise—and this is really phenomenal I think—at 35 to 50 percent a year. By 1990, we could easily see from 100,000 to 150,000 robots being utilized here, with sales topping $2 billion annually. Ford and GM could be using as many as 30,000 robots between them by 1990.

New applications for robotics are appearing virtually daily as their memory and optic capabilities expand. A new generation of robots seems to appear almost monthly now—fruit picking, auto body sanding and painting, welding dirt buckets to bulldozers, drilling bolt holes in F-16's—the list just grows by leaps and bounds.

And the reason is very simple and straightforward: they increase productivity. One robot sands the wings of Boeing's cruise missile in 46 minutes, a job which formerly took several workers 8 hours to perform. General Dynamics has found that their F-16 robots are three to four times more productive than workers alone. GM finds it can purchase a $50,000 robot and operate it at one-third the hourly cost of a skilled worker. And many firms are finding that their robots are paying for themselves in 3 years or less, and are doing the work of anywhere from 1.7 to 6 men and women.

So the rush to robots is easy to understand, especially to American firms who are head-to-head in competition with the Japanese. We developed the first robots nearly 20 years ago. The Japanese Government has heavily subsidized their use and today they have about 60 percent of the robots in the entire world. In fact, Japanese firms utilize over 14,000 robots now, and their enviable productivity records reflect that.

The need to boost productivity and compete with the Japanese and other nations means we just can't turn back the clock. These robots are here to stay. We need to utilize that technology to raise our productivity and maintain existing markets and capture new ones and the jobs which go with them. The issue is how best to deal with the human aspects of their use. That question has two components.

First, can we supply the number of trained assemblers, technicians, maintenance personnel, programers, and operators to build and monitor all of these robots? At my request, the Office of Technology Assessment is evaluating this and other issues related to robotics and automation. Their final report will be completed this fall, but an interim technical memorandum report is being released at this morning's hearing. In particular, it addresses the capability of our Nation to meet the training and retraining demands created by robotics and automation. Mr. John Andelin, OTA's assistant director, will be our first witness and will review his agency's findings.

The second question which is raised by our head-long rush to robotics has a more human touch to it. With the widespread adoption of robotics, will there be an increase in employment or will robotics destroy jobs in this country on a net basis in the years ahead?

Evidence on that question is mixed. One Wall Street expert suggests that each robot will cost the United States four jobs. An analysis by the Arthur D. Little consulting firm predicts that up to 4 million jobs, or one-fourth of our factory work force, could be lost by 1990 to robots. Similar results were projected in a study at Carnegie-Mellon University.

Yet, jobs will be created as well. The Bureau of Labor Statistics predicts that some 800,000 new jobs will be created alone this decade just to produce the robots. And experts at the National Bureau of Standards project that every new robot is going to create from 2 to 4 man-years of work somewhere in our economy. They are predicting that robots are going to create more jobs than they displace.

Our second witness, Mr. Robert Ayres, professor of enginering and public policy at Carnegie-Mellon University, will address this robots versus jobs question in some detail. Mr. Ayres has conducted perhaps the most comprehensive and complete analysis on the unemployment impact of robotics. And we will be hearing both these gentlemen discuss the results and perhaps some comments on the OTA work.

Mr. Andelin, if you will proceed.

STATEMENT OF JOHN ANDELIN, ASSISTANT DIRECTOR, SCIENCE, INFORMATION, AND NATURAL RESOURCES, OFFICE OF TECHNOLOGY ASSESSMENT, ACCOMPANIED BY RICK WEINGARTEN, PROGRAM MANAGER; MARJORY BLUMENTHAL, PROJECT DIRECTOR; BETH BROWN, SENIOR ANALYST; AND JEAN SMITH, ANALYST

Mr. ANDELIN. Thank you, Senator.

I appreciate the opportunity of representing OTA here today. I have brought with me several of the staff that are responsible for the report and I would like to introduce a few of them. Sitting behind me are Rick Weingarten, program manager; Marjory Blumenthal, project director; Beth Brown, education and training specialist; and Jean Smith, working environment and industrial relations specialist.

With your permission, I would like to enter the prepared statement as submitted for the record and paraphrase it to make it somewhat briefer for the oral presentation.

Senator BENTSEN. All right. Fine.

Mr. ANDELIN. Today's hearing is the occasion for the release of our technical memorandum entitled "Automation and the Workplace: Selected Labor, Education, and Training Issues." As you said, this is the first product of the OTA assessment on computerized manufacturing automation which was requested by this subcommittee and others to be completed this fall.

Computerized manufacturing—or more simply programable automation—is an umbrella term that applies to automated equipment and systems that draw on computers. These include robots, which are the primary subject of this morning's hearing; namely, computer-aided design, computer-aided manufacturing, computer-aided process planning, and automated materials handling, storage, and retrieval systems. Some of these are known by acronymns, CAD, CAM, CAPP, and so forth.

While robots seem to attract most of the attention of the media and other public commentators, they are only one component of a larger set of programable, automated technologies. The beginnings of programable automation, in particular CAM, may be found in the development of numerically controlled machine tools in the mid-1950's, while industrial robots were introduced in the early 1960's.

As you said, in spite of this early introduction, current use of programable automation in the United States is quite limited. The 5,000 robots you referred to are the same as our figures. They represent only a few tenths of a percent of the more than 2½ million machine tools in use in the U.S. metal working industries alone. Fewer than 4 percent of that stock of machine tools are believed to be numerically controlled. Thus, little of the eventual impact of programable automation, including robots, on total employment and on education and training has been felt so far. Most of those impacts are yet to come.

At this point in our study, we are unable to provide independent information on the magnitude and timing of these impacts. The technical memorandum released today, however, does discuss procedures for projecting potential employment change associated with programable automation. It also touches on some working environment issues—the human element you mentioned—and describes the nature and modes of delivery of education and training for persons holding or seeking jobs in manufacturing industries. These issues are proper concerns now, since substantial leadtimes are required for developing instructional programs and because more immediate impacts may be experienced in those industries such as transportation, industrial machinery, and electronics, that have been the first to adopt programable automation.

There are some attributes of programable automation that cause the impacts we look for. Those attributes are: One, it has the capacity for processing information as well as performing physical work; two, it can often enhance product quality; three, it has a reprogramability element, which enables the application to the production of a diverse mix of products; and four, it allows direct linkage of production equipment and activities.

These attributes will influence the levels of cost and output for different manufactured goods and productivity. They will also influence the types and range of human activities that can be replaced by machines, the types of new applications providing work for both people and machines, the types of skills required to produce and work with programable automation, and the organization and management of the manufacturing processes themselves.

It is through these influences that programable automation may give rise to the changes in numbers and types of people employed and therefore changes in requirements for education, training, and retraining.

Knowing these factors is a good start, but it is not all that we would like to know. We would like to know how, when, and where programable automation will affect employment and training requirements. Unfortunately, we believe these cannot now be confidently predicted and that they are especially hard to project in detail, for three reasons: First, for a given application, different programable automation equipment and systems can often be used interchangeably or in different combinations or in combination with conventional equipment and systems. From the point of view of the corporation, these may look very much the same. The impact on labor, however, may be quite different from one choice to another.

Second, the extent to which programable automation will be used is itself subject to uncertainty. It will depend upon the rate of technological change, the nature of the technological change, and the pattern of technology diffusion. To complicate matters more, all three of these factors will be affected by actions and conditions in the other countries that produce and use programable automation.

A third reason that it's difficult to project how, when and where programable automation will affect employment and training is that the traits and behavior of the labor force itself influence whether changes in the workplace and the role of labor in manufacturing will translate to unemployment. For example, the impact of labor-saving technologies varies with the rate of growth of the population and with the willingness and ability of people to hold different types of jobs.

Let me say a few words about future labor markets and then I'd like to touch on working environment conditions and say a word about education and training.

With regard to future labor markets, there are many predictions of labor impacts being made today. I would like to discuss quickly some of the methods used to generate these and why we are a bit skeptical of the precision of the results of those.

First of all, past attempts to forecast detailed changes in occupational employment have met with only limited success. They appear to derive from two approaches: one that might be called engineering oriented and the other economics oriented. I'll talk about each of these in sequence.

Engineering estimates are based more or less exclusively on technical aspects of technological change. They are made by describing the capabilities of new automation technologies, projecting their improvements over time, comparing equipment and system capabilities to tasks performed by humans—a one-on-one kind of comparison—and then relating human tasks to different occupations and deriving the number of jobs by occupation that could be assumed by new and future versions of automated equipment and systems. That's an approach similar to that taken by Professor Ayres.

This same kind of approach can be used to derive the number of jobs required to produce the automated equipment and systems. Consequently, one can look on a detailed job-by-job basis at those job or employee categories that will be affected, those that will be replaced, and those that will be required to produce the equipment.

The engineering approach is easily understood and it is a very useful first step in estimating potential employment impacts of programable automation. However, it does have some problems. Let me mention a few.

First, the estimates are easily confounded by errors in projecting future technological capabilities—what programable automation of the next few years will look like.

Second, by relying on these point-by-point comparisons of electronic and mechanical capabilities with human capabilities, the potential for automated equipment and systems to perform jobs in ways not now performed by humans, or perform jobs that are poorly done or not done at all by humans, may be missed. The failure may result in either overestimation or underestimation of job displacement.

Third, the engineering analysis typically yields a technically ideal mix of humans and equipment, but as the Congress is more aware than many, the actual mix would reflect complex management and implementation considerations, the interest of the individuals involved in the specific activities. Finally, engineering-based estimates of job displacement frequently assume that labor force characteristics remain constant, another source of potential bias.

Thus, engineering-based estimates are an important first step, but questions should be raised in evaluating any such estimates.

Let me look at another commonly taken approach: economic estimates. They're made by explicitly evaluating several factors, in addition to technology, that impinge on employment demands, such as prices and production levels. They're inherently more comprehensive than engineering estimates because they rely on macroeconomic models, large-scale mathematical models that describe how an economy uses its various resources to produce and consume goods and services. This approach prevents undue emphasis on single influences, such as technology change, and in a sense it prevents a certain amount of double counting.

On the other hand, the high level of aggregation of macroeconomic models renders them impractical for gaging possible employment change at the company-by-company level. Also, the use of these models carries the risk of oversimplifying complex processes and conveying an impression of greater analytical thoroughness than may actually exist.

In short, with regard to the projections of future labor markets, we believe that evaluating the effects of the increased use of programable automation on employment is extremely difficult. Consequently, we recommend that statements about the future labor impacts of programable automation, especially on a national level, should be received warily and that the underlying assumptions should be fully explored.

I'd now like to shift to the working environment issue and comment that it is not expressed in length in the prepared statement, but that does not in any way reflect our impression of its importance. It reflects more the interest we believe the committee to have at this morning's hearing, and it reflects somewhat the state of our own investigation into it. It will have a considerably larger role in our final assessment.

Programable automation may change not only the numbers and types of people working in manufacturing, but also the circumstances of the work, what may be called the working environment. As I say, we've only begun to examine this set of issues, but we are struck by its importance already. How programable automation affects the working environment will depend on how it is applied. As I mentioned earlier, there are different kinds of programable automation systems, sometimes mixed in with conventional equipment, that provide roughly the same benefit to the corporation but have different impacts on labor. Those kinds of differences will enter into the labor-management interactions and will affect the way in which programable automation affects the labor force.

Changes in the working environment may be experienced in many ways. Occupational safety and health risks may change. For example, automating metalworking tasks may reduce occupational hazards. On the other hand, increasing use of video display terminals might create new types of problems. Also, the introduction of programable automation is likely to lead to changes in job content, including task variety and degree of mental challenge.

Finally, Senator, I would like to discuss the education and training aspects of the job shifts, displacement, or unemployment that may take place. In particular, the increased application of programable automation in manufacturing may alter the demand for different types of employees and the nature of different jobs. As a result, it may trigger widespread changes in education and training requirements, not only for people holding or seeking to hold jobs in the manufacturing sector, but also for people in other economic sectors. This, by the way, reinforces a similar conclusion reached late last year in an OTA study, "Informational Technology and Its Impact on American Education."

As new technologies, such as programable automation, begin to affect the economy, individuals, industry and labor organizations respond by seeking out and providing education and training. As I will discuss, this is a widespread phenomenon. We do not know at this point, however, how much of the education and training is sought or provided as a means of adapting to programable automation or changing manufacturing technology in general.

I'd like to mention a few participants in the provision of instruction. First, private industry. It is a major provider of instruction. The American Society for Training and Development estimates that U.S. industry now spends approximately $40 billion annually on education and training programs for employees. But these educational benefits are not evenly distributed. It is estimated that technical instruction beyond apprenticeship is infrequently offered by companies to employees other than engineers and data processing personnel. In smaller firms, little or no technical or skills-related instruction is offered. These firms traditionally rely on on-the-job training which is less expensive than formal instructional programs.

Labor unions are also involved in instruction but usually not as providers. Since the 1960's, labor unions representing manufacturing workers have taken a growing interest in securing education and training benefits for their members through the collective bargaining process, reflecting an awâreness of the potential impacts of technology on their members. The United Auto Workers and the International Association of Machinists are among the most active unions in promoting technology-related education and training opportunities for their respective membership. For example, 1982 agreements that the United Auto Workers reached with Ford Motor Co., General Motors, and International Harvester contain provisions for training and retraining employees, both current employees as well as those laid off. In addition, each contract calls for the establishment of a joint union-management employee development and training committee through which special instructional assistance will be provided to members who are displaced by new technologies, by new techniques of production or by shifts in customer preference.

As another example, the International Association of Machinists has developed model contract language for its locals that includes provisions for dealing with in-plant technological change.

Of course, labor unions and industry are not the only parties involved in educating the labor force and in altering instruction in response to new technology. OTA has identified several public school systems, technical schools, community colleges, engineering programs and CETA-funded programs that provide instruction for programable automation.

From another perspective, in order to identify the state-of-the-art of instruction for new manufacturing technology, OTA sponsored a survey of representatives of companies that produce programable automation equipment and systems, companies that do use or may use programable automation in their facilities, labor unions, traditional and nontraditional educational institutions, and others familiar with instruction design and delivery.

Findings from 506 interviews indicate that although 40 percent of the manufacturing plants responding used some form of programable automation, only half of those sponsored or conducted education and training for the new technology. Among plants currently not offering education and training programs of this type, less than one in five indicated any plans to implement programs in the future.

In contrast to the relatively low proportion of user firms that sponsor and conduct training for new technology, 93 percent of the companies that produce automated equipment and systems provide some instruction for their customers. However, the nature and scope of such instruction is quite limited. About a third of these companies indicated that they were currently ready to provide all instruction they felt necessary for production line employees.

Because programable automation is only now presenting the prospect of major employment and training changes, there are many questions about appropriate curricula and targeting. The availability of such instruction is growing, but most indicators suggest that training and retraining requirements for programable automation are at this point poorly defined. There is little evidence that any group, including private industry, is seriously considering the long-range implications for occupational skills requirements and instructional capabilities of growth in the production and use of programable automation.

Some of the issues to be faced by those who provide instruction are the following:

(1) How and by whom the need for technological literacy will be addressed;

(2) What types of counseling and instructional systems, both short-term and long-range, are needed;

(3) How to initiate appropriate curriculum design processes; and

(4) What funding sources could be used for curriculum design and implementation.

In conclusion, Senator Bentsen, the points that we would like to stress now are the following: First, robots are but one component of a larger programable automation phenomenon. Second, specific—that is, occupational and industrial—employment impacts are hard to predict, and we lack confidence in those predictions currently publicized. Third, changes in the numbers of jobs are only one of the consequences of increasing use of programable automation, another important one being changes in the quality of jobs. Fourth and finally, while new instructional programs for persons who may use or produce programable automation are emerging from several sources, curriculum development, change, and delivery are not proceeding in a coordinated fashion.

Thank you, Senator.

[The prepared statement of Mr. Andelin, together with the press release referred to, follows:]

PREPARED STATEMENT OF JOHN ANDELIN

Manufacturing Automation: Selected Employment and Education Issues

Good morning. My name is John Andelin; I am an Assistant Director of the Office of Technology Assessment, where I manage the Science, Information, and Natural Resources Division. With me today are Rick Weingarten, Manager of the Communications and Information Technologies Program; Marjory Blumenthal, Project Director for the assessment entitled Computerized Manufacturing Automation: Employment, Education, and the Workplace; Beth Brown, Senior Analyst and education and training specialist for that assessment; and Jean Smith, Analyst and working environment and industrial relations specialist for that assessment.

Today's hearing is the occasion for the release of an OTA Technical Memorandum entitled Automation and the Workplace: Selected Labor, Education, and Training Issues. This technical memorandum is the first product of the ongoing assessment just mentioned. This assessment itself was requested by this Committee, together with the Senate Committees on Labor and Human Resources and Commerce, Science, and Transportation, and the Subcommittee on Labor Standards of the House Committee on Education and Labor. It will be completed this Fall.

Computerized manufacturing--or, more simply, programmable automation--is an umbrella term that applies to several types of automated equipment and systems that draw on computers, including robots, computer-aided design or CAD, computer-aided manufacturing or CAM, computer-aided process planning or CAPP, and automated materials handling, storage, and retrieval systems. While robots seem to attract most of the attention of the media and other public commentators, it is important to realize that robots are only one component of a larger set of programmable automated technologies. It is also important to recognize that programmable automation technologies are not new. For example, the beginnings of CAM may be found in the development of numerically-controlled machine tools in the mid-1950s, while industrial robots were introduced in the early 1960s.

In spite of this early introduction, current use of programmable automation in the United States is limited. The Robot Institute of America, for example, reported that fewer than 5,000 robots were believed to be in use in the United States in 1981--only a few tenths of a percent of the 2.6 million machine tools reported by the National Machine Tool Builders' Association to be in use in U.S. metalworking industries alone by the late 1970s. Also, of that stock of machine tools, fewer than 4% were believed to be numerically controlled. Thus, to the extent that the rate of introduction of programmable automation in manufacturing increases, which it is generally expected to do, any major impacts of programmable automation on total employment and on education and training needs are likely to be felt in the future.

At this point in our study, we are unable to provide independent information on the magnitude and timing of any such impacts. The Technical

Memorandum released today, however, does discuss procedures for projecting potential employment change associated with programmable automation. It also touches on some working environment issues and describes the nature and modes of delivery of education and training for persons holding or seeking jobs in manufacturing industries. These issues, gauging possible shifts in skill requirements and resulting instructional needs, are proper concerns now since substantial lead times are required for developing instructional programs and because more immediate impacts may be experienced in industries such as transportation equipment, industrial machinery, and electronics, which have been the first to adopt programmable automation. (An August 1982 OTA survey of establishments in those industries revealed that 40% of respondents used some form of programmable automation.)

Four attributes of programmable automation are key to understanding their ramifications for the labor force: (1) capacity for information processing as well as physical work; (2) capacity for enhancing product quality; (3) reprogrammability, enabling their application to the production of a diverse mix of products; and (4) capacity for linking production equipment and activities. These attributes will influence the types of products that can be produced with programmable automation and their costs. Moreover, these attributes will influence (1) the types and range of human activities that can be replaced by machines; (2) the types of new applications providing work for both people and machines; (3) the types of skills required to produce and work with programmable automation; and (4) the organization and management of manufacturing processes. It is through such influences on the role of labor in manufacturing that programmable automation may give rise to changes in the numbers and types of people employed, and therefore changes in requirements for education, training, and retraining.

How, when, and where programmable automation affects employment and training requirements cannot be confidently predicted, and are even hard to project in detail, for three reasons: First, the design and implementation of programmable automated equipment and systems vary widely among users. From a technical standpoint, programmable automation comprises a set of equipment and systems technologies that can be used interchangeably, to some extent; in different combinations; and in combination with conventional equipment and systems. The impact on labor, however, may be quite different from one system to another.

Second, the extent to which programmable automation will be used is itself subject to uncertainty. It will depend on: (a) the rate of technological change (in particular, the rate at which automation innovations are commercialized); (b) the nature of the technological change (programmable automation, for example, changes production processes through the use of new equipment but it may also be associated with new management practices, which themselves are a form of new technology); and (c) the pattern of technology diffusion (although programmable automation is currently concentrated in metalworking and electronics industries, whether and when it spreads to other industries influences the mix of employment opportunities of current and prospective members of the labor force.) To complicate matters more, all three factors will be affected by actions and conditions in other countries that produce and use programmable automation.

Third, the traits and behavior of the labor force influence whether changes in the workplace and the role of labor in manufacturing translate into unemployment. For example, the impact of labor-saving technologies varies with the rate of growth of the population, and with the willingness and ability of people to hold different types of jobs.

In short, evaluating the effects of increased use of programmable automation on employment is extremely difficult. Consequently, statements about the future labor impacts of programmable automation, especially on a national level, should be received warily and their underlying assumptions fully explored.

Future Labor Markets. Since many predictions of labor impacts are being made, I would like to discuss some of the methods used to generate estimates of future occupational employment. Historically, attempts to forecast detailed changes in occupational employment have met with limited success. OTA reviews the ways in which occupational forecasts are made, and provides general comments and criticisms in the technical memorandum released today.

Publicized estimates of employment change associated with programmable automation appear to derive from two approaches, one an engineering-oriented approach, and one an economics-oriented approach. I will briefly review those approaches and some of their characteristics.

Engineering estimates are based more or less exclusively on technical aspects of technological change. They are made by describing the capabilities of new automation technologies, projecting improvements over time, comparing equipment and system capabilities to tasks performed by humans, relating human tasks to different occupations, and deriving the number of jobs, by occupation, that could be assumed by new and future versions of automated equipment and systems. A similar approach can be used to derive the number of jobs required to produce automated equipment and systems.

The engineering approach is easily understood, and it is a useful first step in estimating potential employment impacts of programmable automation. However, it is subject to the following problems: First, these estimates are easily confounded by errors in projecting future technological capabilities.

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Second, by relying on point-by-point comparisons of electronic and mechanical capabilities with human capabilities, the potential for automated equipment and systems to either perform jobs in ways other than simulation of human behavior, or to perform jobs that are poorly done or not done at all by humans, may be missed. This failure may result in over- or under-estimation of job displacement.

Third, the result of an engineering analysis is typically a "technically" ideal mix of humans and equipment, while the actual mix may reflect complex management and implementation considerations. Finally, engineering-based estimates of job displacement frequently assume that labor force characteristics remain constant, another source of potential bias.

Economic estimates are made by explicitly evaluating several factors, in addition to technology, that impinge on employment demands, such as prices and production levels. They rely on engineering analyses for descriptions of the effects of technologies on industry's requirements for inputs to production, including labor. The most detailed economic estimates of employment change come from models that include input-output components. Projections by the Bureau of Labor Statistics, for example, are made by combining an input-output model with other models that forecast change in the labor force and in the level and pattern of economic activity, and with descriptions of industry staffing patterns.

Economic estimates are inherently more comprehensive than engineering estimates because they rely on macroeconomic models. Macroeconomic models are comprised of mathematical equations that describe how an economy uses its resources to produce and consume goods and services. This framework prevents overattributing employment changes to single influences such as technology change. On the other hand, their high level of aggregation renders them impractical for gauging possible employment change at the company level. Also, the use of large-scale models carries the risk of oversimplifying complex processes and conveying an impression of greater analytical thoroughness than may actually exist.

Other shortcomings of economic estimates include the following: First, economic models that project labor supply and industrial output separately may not capture the complex interactions of demographic and economic factors that influence the growth of the labor force and change in labor force participation by different groups within the population. Nor may they capture differences in the quality of the labor force, differences which may govern the ability of the labor force to adapt to changes in economic activity.

Second, economic models tend to project future capital stock by extrapolating from past conditions and future staffing patterns by reflecting past or current practices. In doing so, they may miss some important changes in equipment technologies and incorrectly project employment associated with new technologies that may lead to changes in the organization of production and in management practices.

In sum, the OTA review of occupational employment projection practices suggests, at this time, that satisfactory projections should take into account several factors that contribute to the direct and indirect effects of programmable automation.

Working Environment. Programmable automation may change not only the numbers and types of people working in manufacturing, but also the circumstances of work—what may be called the working environment. We have only begun to examine this set of issues, but we are struck by its importance. How programmable automation affects the working environment will depend on how it is applied. Changes in the working environment may be experienced in many ways. For example, occupational safety and health risks may change, as automated metalworking tasks may reduce occupational hazards, while increasing use of video display terminals might create new types of problems. Also, the introduction of programmable automation may lead to changes in job content, including task variety and degree of mental challenge.

Education and Training. Because it may alter the demand for different types of employees and the nature of different jobs, the increased application of programmable automation in manufacturing can trigger widespread changes in education and training requirements. Programmable automation may thereby augment the influences of other technologies on the U.S. economy and its instructional needs, which were documented in a recent OTA study entitled Informational Technology and its Impact on American Education. The utilization of programmable automation, depending upon its impact on employment levels within specific occupations, may not only alter instructional requirements for people holding or seeking to hold jobs in the manufacturing sector, but it may also necessitate the retraining of individuals for occupations in other sectors.

As new technologies, such as programmable automation, begin to affect the economy, individuals, industry and labor organizations respond by seeking out (and providing) education and training. We do not know, however, how much of this education and training is sought or provided as a means of adapting to programmable automation or changing manufacturing technology in general. (Overall, we do know that professional and technical employees, and people between the ages of 17 and 35, tend to participate in education and training more than other groups. This is noteworthy because other groups in the labor force, such as older semi-skilled and skilled production line workers, may be at great risk when programmable automation is introduced in their facilities.)

Private industry is a major provider of instruction. The American Society for Training and Development estimates that U.S. industry now spends approximately $40 billion annually on education and training programs for employees. They and other sources also estimate that technical instruction beyond apprenticeship is infrequently offered by companies to employees other than engineers and data processing personnel. This appears to be due to the relatively high cost, equipment requirements, and stringent instructor qualifications associated with such instruction. In smaller firms, little or no technical or skills-related instruction is offered. These firms traditionally rely on on-the-job training, which is less expensive than formal instructional programs.

Labor organizations are also involved in instruction, but usually not as providers. Since the 1960's, labor unions representing manufacturing workers have taken a growing interest in securing education and training benefits for their members through the collective bargaining process, reflecting an awareness of the potential impacts of technology on their members. The United Auto Workers and the International Association of Machinists are among the most active unions in promoting technology-related education and training opportunities for their respective memberships. For example, 1982 agreements that the United Auto Workers reached with Ford Motor Company, General Motors and International Harvester contain provisions for training and retraining current employees as well as those laid off. In addition, each contract calls for the establishment of a joint union-management employee development and training committee through which special instructional assistance will be provided to members who are displaced by new technologies, new techniques of production and "shifts in customer preference." Employees both skilled and semiskilled are covered under other provisions of the agreements and are

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eligible to participate in upgrade training designed to sharpen job skills and to familiarize them with the state-of-the-art of technology being utilized in their plants.

The International Association of Machinists has developed model contract language for its locals that includes provisions for dealing with in-plant technological change. The language on training benefits, for example, calls for instruction during working hours at company expense and at prevailing wage rates. Model contract provisions also state that senior employees should have first claim on training opportunities. Other provisions pertain to training for jobs not necessarily associated with new technology, in cases where "...either the new technology requires substantially fewer workers or present employees are not capable of successful retraining."

Of course, labor organizations and industry are not the only parties involved in educating the labor force and in altering instruction in response to new technology in general and programmable automation in particular. In research performed to date, OTA also has identified several public school systems, technical schools, community colleges, engineering programs and CETA-funded programs that provide instruction for programmable automation.

In order to identify the state-of-the-art of instruction for new manufacturing technology, OTA sponsored a survey of representatives of companies that produce programmable automation equipment and systems, companies that do or may utilize programmable automation in their facilities, as well as labor unions, traditional and nontraditonal educational institutions, and others familiar with instructional design and delivery. Findings from 506 interviews indicate that although 40 percent of the manufacturing plants surveyed used some form of programmable automation, only 22 percent sponsored or conducted education and training for the new technology. Among plants currently not offering education and training programs of this type, only 18 percent indicated any plans to implement programs in the future.

In contrast to the low proportion of firms applying the technology in their manufacturing facilities who also sponsored and conducted training for new technology, 93 percent of the companies who produce automated equipment and systems provide some form of instruction for their customers. The nature and scope of the instruction these firms offer is quite limited. Over 80 percent provide only single courses and very few provide any sort of graduated series of courses. Furthermore, only about a third of these companies indicated that they were currently ready to provide all instruction they felt necessary for production line employees.

Because programmable automation is only now presenting the prospect of major employment and training changes, many questions about appropriate curricula and targeting for instructional programs remain to be resolved. Although the availability of such instruction is growing, current views of representatives from industry, labor, the educational community and government are consistent with other indicators in suggesting that training and retraining requirements for programmable automation are, at this point, poorly defined. Even within specific geographic areas, programs initiated to address changing instructional requirements do not, in the aggregate, represent a coordinated approach to defining instructional needs associated with new industrial processes.

While it is too soon to know how widespread the applications of programmable automation will be, there is little evidence that any group--including private industry--is seriously considering the long-range implications for occupational skills requirements and instructional capacities of growth in the production and use of programmable automation. Among the pressing issues facing those who provide instruction, in response to the spread of programmable automation, are:

1. how and by whom the need for technological literacy will be addressed;
2. the types of short-term and long-range counseling and instructional systems needed;
3. the initiation of appropriate curriculum design processes; and
4. funding sources for curriculum design and implementation, including equipment.

In conclusion, Mr. Chairman, the points that we would like to stress now are the following: First, robots are but one component of a larger programmable automation phenomenon. Second, specific--that is, occupational and industrial--employment impacts are hard to predict, and we lack confidence in those predictions currently publicized. Third, changes in the numbers of jobs are only a part of the consequences of automation, another important part being changes in the quality of jobs. Fourth and finally, while new instructional programs for persons who may use or produce programmable automation are emerging from several sources, curriculum development, change, and delivery are not proceeding in a coordinated fashion.

March 18, 1983
OTA News Advisory

Contact: Annette Taylor
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OTA RELEASES STUDY ON AUTOMATION & THE WORKPLACE: SELECTED LABOR, EDUCATION & TRAINING ISSUES

The Congressional Office of Technology Assessment (OTA) has released a technical memorandum* that provides background material for evaluating the labor, education, and training implications of programmable automation technology. The technical memorandum was released at hearings held today by the Joint Economic Committee. The material covered in the technical memorandum presents preliminary components of a larger OTA assessment titled "Computerized Factory Automation: Education, Employment, and the Workplace", which is scheduled for completion late in 1983.

While popular definition of programmable automation is often confined to robotics, the term also applies to computer-aided design and manufacturing, computer-aided process planning, automated materials handling, and automated storage and retrieval systems. Such applications in manufacturing are likely to affect employment, education, and training in most manufacturing sectors sometime in the future; the greatest impacts will be felt over

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*OTA Technical Memoranda deal with specific subjects analyzed in recent OTA reports or with projects presently in progress at OTA. They are issued at the request of Members of Congress who are engaged in committee legislative actions which are expected to be resolved before OTA completes its assessment. They are neither reviewed nor approved by the Technology Assessment Board.

the next two decades in industries that are already adopting the technology -- transportation equipment, industrial machinery, and electronics.

OTA's technical memorandum describes the difficulties in attempting to make detailed predictions about employment requirements and evaluates some of the methods commonly used to generate such forecasts. OTA also outlines several of the factors that need to be considered in any plausible projection of the effects of programmable automation on employment levels, such as changes in the attributes of the labor force.

The introduction of programmable automation is likely to affect such areas of the working environment as worker safety and health, human factors, job content, and structure of work, according to OTA. Many of the potential effects are contingent on the ways in which the technology is applied and implemented.

According to OTA, education and training requirements for people holding or seeking jobs in the manufacturing sector are likely to change as the increasing use of programmable automation alters the organization of the manufacturing process, the character of the production line, the occupational mix and the human-machine relationship. OTA has identified several public school systems, technical schools, community colleges, engineering programs and Federally-funded programs that provide instruction for programmable automation. However, current views suggest that training and retraining requirements are, at this point, poorly defined, and programs initiated to address changing instructional requirements do not represent a coordinated approach to defining instructional needs associated with new industrial processes.

While it is too soon to know how widespread the applications of programmable automation will be, there is little evidence that any group -- including private industry -- is seriously considering the long-range implications for occupational skills requirements and instructional capacities of growth in the production and use of programmable automation. The results of an OTA-sponsored survey indicate that although 40 percent of the manufacturing plants responding used some form of programmable automation, only 22 percent of the users sponsored or conducted education and training for the new technology. In contrast, 93 percent of the companies who produce automated equipment and systems provide some form of limited instruction for their customers.

OTA is a nonpartisan analytic support agency which serves the U.S. Congress. Its purpose is to help Congress deal with the complex and often highly technical issues that increasingly confront our society.

Copies of the technical memorandum, "Automation and the Workplace: Selected Labor, Education and Training Issues," are available at the U.S. Government Printing Office (GPO), Superintendent of Documents, Washington, D.C. 20402. The GPO stock number is 052-003-00900-5; the price is $5.50.

Senator BENTSEN. Thank you, Mr. Andelin, and I would like you to stay for questions after we let Mr. Ayres comment.

There is no question that there are a lot of things yet to be resolved in trying to give definitive forecasts as to the effect of robotics on job loss and change in types of jobs. But, the evidence available shows that there is going to be a major change for a lot of people in the types of jobs they do and that creates a major retraining requirement. It is terribly important for us in the Congress to have your best judgment regarding training requirements associated with robotics, with all of the imponderables that are there. We have to have the experts give us their best guess, if that's what it is, in order that we can see what the private sector is doing with additional training and what we have to do in trying to assist with education and vocational education. I will be looking forward to your final report this fall—although I'm sure it won't be final—and I don't want you to just hedge, hedge, hedge. I want you to give us your best judgment on what you think is going to happen and put some numbers in that report with all the qualifications you want to put on it.

Mr. ANDELIN. Senator, your directive is quite clear. I don't wish my statement in any way to be construed as saying that we don't recommend that people, including ourselves, pursue those kinds of specific numbers by any techniques that they wish to choose. What we are saying is that any and all of these projections, including our own, should be subject to very careful scrutiny as to the assumptions built in. As the course of the future does evolve we can see which elements of which projections are in fact coming true, so to speak, and which ones are not. We do not wish to be deceived by an appearance of certainty today. We rather wish to recognize a reality that the future is pretty vague to all of us.

Senator BENTSEN. Any time you have an industry that's growing at the rate of 35 to 50 percent a year compounded, as the predictions show, any time you have some of the estimates that have been presented in the press as to how many jobs will be lost to robotics—there is a convulsion, there is a revolution taking place in the work force. Having the ability to adjust to that is terribly important to this country and to those people involved in that process.

That is why we have to have your best judgment in that regard.

Mr. Ayres, we're pleased to have you. You may proceed.

STATEMENT OF ROBERT U. AYRES, PROFESSOR OF ENGINEERING AND PUBLIC POLICY, CARNEGIE-MELLON UNIVERSITY

Mr. AYRES. Thank you, Senator Bentsen. I'm pleased to be on the ground again.

Senator BENTSEN. We've had some pretty mucky weather. Did you come into National?

Mr. AYRES. Yes. I'm very glad to have this opportunity to discuss with you the potential implications of robotics and automation for employment in the United States. I will also comment briefly on the related questions of education, training, and retraining.

First, let me explain why I think the issue is indeed one that deserves explicit attention by the Congress. Many economists express the view that robotics—in the general sense of the term, including a variety of emerging industrial applications of computers—is merely a continuation of historical trends that date back to the first industrial revolution, and earlier. During all that period, machines have been extending human physical capabilities and, in some circumstances, displacing human workers. In fact, had this not occurred, most American families would still be working on farms and struggling to produce enough surplus food to exchange for woolen cloth, horseshoes and nails, needles and thread, and so on.

It is perfectly true that robotics is a form of automation, and that automation is a continuation of mechanization, which has been going on for a long time.

It is also quite true that many kinds of jobs have been more or less eliminated. To begin with, the vast majority of farm labor jobs have disappeared. I assume none of us is too distressed over not having to get up at 5 a.m. and spend 12 hours hoeing or walking up and down a field following a mule. Mechanization of farms also displaced the village blacksmiths who made their living shoeing horses. More recently, mechanization has eliminated 80 percent of the coal-mining jobs that existed formerly. The list goes on. On the whole, I assume most people would agree that our society is far better off today without those jobs than it would have been if we had somehow preserved them.

In fact, a number of obsolete jobs have been preserved, mainly by union power. Sometimes the old job title hangs on, as in the case of the railroad firemen. More often, union work rules require three or four men to do a job that could be done perfectly well by one. In most cases where this sort of job preservation has been practiced, the industry is now in deep trouble with more efficient competitors, domestic or foreign.

I am well aware, too, that a major national debate occurred in the early 1960's on virtually the same issue that has arisen again lately; namely, the impact of computerized automation on employment. There were a number of panicky predictions of mass unemployment at that time, and a number of social thinkers advocated fairly radical income redistribution programs as a possible response. One of them was Milton Friedman, who proposed the so-called negative income tax, just before becoming an adviser to Senator Barry Goldwater's 1964 Presidential campaign.

Obviously, the enormous proliferation of computers through the 1960's and 1970's did not, in fact, cause much, if any, unemployment. True, a few categories of jobs have been eliminated, mostly clerical, but up until now most of the applications of computers have been to do things that simply could not have been done previously. The computerized airline reservation system is an example. Without it, the massive expansion of airline services over the past two decades would not have been possible. On the other hand, it turned out to be very much harder to use computers to operate machine tools—far less whole factories—than anybody dreamed 20 years ago. Thus, computers had very little impact on the factory floor until the mid-1970's, and even today at least 95 percent of all machine tools in the United States are probably still manually operated. The figure was 98 percent in

1979. It is perhaps more relevant to say that, even after 20 years, something like 60 to 70 percent of the aggregate output of the metalworking industries is produced on noncomputer-controlled machines.

The number of industrial robots in use in the United States is now over 5,000, mostly in die casting shops and foundries, and doing spot-welding and spray painting on auto assembly lines. A few thousand workers have been directly displaced, but probably most of them were moved to other jobs in the same plant. In any case, the contribution of robotics to unemployment, so far, has been negligible in comparison to other factors such as a depressed economy and foreign competition. Yet, as I said at the outset, I believe it is important to consider seriously the potential for future job displacement by robots in industry over the next several decades.

My reasoning is as follows:

One, while robotics is a kind of automation, and automation per se is not new, robots are the first kind of automation that directly replace workers by doing what many workers do; namely, to manipulate parts, load, unload, and operate other kinds of machines and/or portable tools.

Two, as a logical extension of paragraph 1 above, the primary—almost the sole—justification for purchasing industrial robots is to eliminate workers. While robots could theoretically be justified in terms of increased output, improved product quality or flexibility in the manufacturing process, these benefits are generally more hypothetical and harder to measure. What is easily measured in quantitative terms is reduced labor hours, and under the financial guidelines for justifying new investment in most firms, this is the measure that counts.

Three, workers understand the motivation for installing robots described above as well as their employers do. Thus, they tend to regard robotics as a direct threat to their jobs.

Four, the threat, as I described, is regionally concentrated in industries that have a lot of highly paid semiskilled operatives doing routine jobs. This description applies especially to the metalworking sectors—Standard Industrial Classification 33–38—which are particularly concentrated in the five Great Lakes States grouped around Lake Michigan, Lake Ontario, Michigan, Ohio, Indiana, Illinois, and Wisconsin, where about half of all metalworking employment is located. Moreover, these States generally have the oldest plants and the most highly paid workers.

Five, the metalworking industries as a group are fundamental to the industrial strength of the United States, but they are all under heavy competitive pressure from abroad. Moreover, their markets are now mostly growing slowly or not at all. The choice facing many firms in these industries is to cut costs dramatically or shut down. Looking at it this way, robotics could be essential to a corporate survival strategy.

Six, the stage is set, therefore, for a no-win confrontation where unions will be pressured by their members to demand a variety of concessions to protect jobs, and yet the increasing burden on marginal firms is economically unsupportable. The burden of unemployment on the northern tier of States is also becoming unsupportable by the States. Some unions and corporations are already turning toward protectionist policies that would simply institutionalize U.S. industrial inefficiency, not to mention triggering retaliatory measures against U.S. exporters.

This line of argument leads me to conclude that active intervention by the Federal Government is becoming essential. Only the Federal Government has the resources to deal with the problem.

The problem does not arise from the absolute numbers of workers "at risk." In fact, all the evidence at hand—at least that I have seen—suggests that the numbers will not be very large through the 1980's, and that declining net rates of growth of the labor force in the 1980's and 1990's could easily take care of the problem by attrition. Our estimates of the numbers involved have been given in several publications, which I have made available to the committee staff. But the absolute numbers do not really tell the story, and I could summarize them briefly now if you wish me to. Should I do that?

Senator BENTSEN. We can do that later. Thank you.

Mr. AYRES. I'll save that for later, but the absolute numbers do not really tell the story.

The problem, as I said, arises from the fact that the vulnerable categories of semiskilled workers are geographically concentrated in a region that is already economically troubled. This has two important consequences. First, it increases their economic vulnerability. A few displaced workers in the Southwest or Western States have a far better chance of finding comparable work in a diversified and prosperous area than would thousands of workers in Dayton, Fort Wayne, or Peoria—cities with a few very large plants—if one plant closes, the city faces instant disaster. Moreover, workers find it very difficult to move elsewhere, if they live in cities with a declining economic base and no buyers for their homes—where all their meager savings are tied up.

The other consequence of concentration is that the vulnerable workers can cause trouble if they are sufficiently fearful. I hesitate to predict a wave of neo-Luddism in the United States, but the conditions for it seem to exist. If shortsighted employers see the present depressed economic conditions as a long-awaited opportunity for union busting, the worker will probably become even more fearful. The results could be perverse and damaging to both workers and employers, and to the country as a whole.

It seems particularly appropriate to borrow Franklin Roosevelt's phrase: "What we have to fear is fear itself," speaking of the fear of the workers. The role of the Federal Government, in the last analysis, must be to allay that fear by creating a meaningful human resources policy for the United States.

This is not the time or place for a detailed discussion of the whole range of policy options. Education, training, and retraining are certainly part of the package, though I think there is some danger of overemphasizing their importance, at least as a short-run answer. It is quite clear, for instance, that retraining of older semiskilled workers will be a difficult undertaking at best. It will be futile if there are no local jobs for these workers after they are retrained. In this context the whole question of interstate competition for jobs, and interstate allocation of Federal dollars must be addressed, however difficult this may be.

To return to the specific concerns being addressed today, I can only approve the call for better statistical data and improved economic forecasting models. As an educator, I can also hardly disapprove of increased emphasis on education and training. Perhaps it would be more accurate to say that I believe that the recent cutbacks in Federal support for education and training are shortsighted and damaging to our longrun national competitive postures vis-a-vis Japan, the EEC and the U.S.S.R. On the other hand, a restructuring of the Federal role seems to me desirable. Up until now the technologically displaced older worker has been essentially neglected, which seems to me not only inequitable but possibly dangerous to the social and political stability of this country.

Senator BENTSEN. Thank you, Mr. Ayres.

I think your point about the middle-aged worker is a very pertinent one because a worker looks at something like this [pointing to robot exhibit] and says, "You mean that is going to replace me and two, three, or four of us?" That is very frightening and he wonders where he can go and what will happen to him. That fear moves through the work force and you could have a situation where they reject it all, and we become noncompetitive in the world.

So we have to be able to better understand and translate and interpret what is going to happen and what are some possible solutions and things that can be done to ease the transition by workers into other kinds of jobs.

I think your point about the concern for the middle-age worker is a very important one. We have not done the job in this country of training and education we should for those type workers.

I heard Mr. Andelin referring to some of the additional private sector training taking place. Do either one of you see a trend among private employers to a better acceptance of the need for training for automation and robots in order to be able to achieve increases in productivity? Is the private sector responding to it?

Mr. ANDELIN. As I said in the prepared statement, of the survey of facilities that are presently using or manufacturing programable automation, about half of the companies that use it have some kind of training for their employees; and of those selling the equipment, almost all have some kind of training programs for using them.

Senator BENTSEN. Is this more than we have seen in the past?

Mr. ANDELIN. Well, since the technology didn't exist, sure but industry already has a very large role in employee education and training in general; $40 billion a year is one number that's been quoted to us. We haven't independently checked it, but it's a huge amount of education and training.

We also see that there are some unions, some elements of labor, depending upon their skills, that accept the introduction of the new technologies more easily. The IBEW has a joint program with industry to change electricians into programable automation workers; so there's considerable variation.

That's one of the problems that we have when we talk about the large models. They miss the fine-scale detail. And the problem with the fine-scale models is it's hard to aggregate them.

What we see missing is a coordination of the activities in curricula development and determination of instructional goals. The kind of work that Mr. Ayres is doing needs to be well understood and checked out carefully. Without knowing where the jobs will be shifting, it's a little hard to know what curricula and what kind of training are necessary. The kind of work he's doing will lead to better understanding of where the displacements will occur and that's when industry and the educators—conventional and unconventional educators—have a better idea of where the training should occur.

Senator BENTSEN. Mr. Andelin, I listen to your comments about the difficulty in trying to pin numbers down and I understand that. You say the impact of robotics on employment in this decade will be relatively small.

Mr. ANDELIN. I think I said that it's been small so far because there's too little deployment, and so whatever impacts there are are yet to come.

Senator BENTSEN. But again, I get back to the point. If the use of robots is growing 35 to 50 percent a year compounded, that has to have a major impact. I see the auto industry says that 1.7 jobs are lost—the UAW expects to lose 20 percent or 200,000 members by 1990—to robots, despite a healthy estimated 15 percent growth in auto production. Up to 25 percent of our factory workers, 4 million men and women, could lose their jobs by 1990 according to an analysis by the Arthur D. Little Co. GE has found that automation could replace half of their 37,000 workers. That's their estimate.

Mr. Ayres, a Wall Street Journal article, which quoted your 1981 study, says that the simple first generation robots widely used today could replace 1.2 million workers by 1990; that the second generation robots coming along with sophisticated optic capabilities could replace over 3 million jobs and could potentially jeopardize almost 4 million other jobs as well. I think that is a pretty major impact—a major change in the types of jobs available in our manufacturing sector. You made the point on education that I thoroughly agree with. We have to have that type of education and retraining investment, but we can't sell it as a public sector obligation unless we have an understanding of it.

I'm curious to know about the Japanese. The Japanese have approximately 60 percent of all robots despite the fact that we first started out with them. They have adapted them to their manufacturing processes much faster than we have, with substantial subsidies by the Government. How much have you gentlemen studied what has happened there? If they are that much further along than we are, then perhaps we can examine some of the things that have happened there and better plan for what may take place here.

Mr. AYRES. Well, I think I have with me the clipping—perhaps I don't have it—but apparently there's beginning to be a resistance in the Japanese work force.

Senator BENTSEN. That's right. I saw a recent series of film clips where they were talking about the Japanese trying to build a factory that had no workers. Yet, they had a tough time doing it, as I recall. The night shift had only one worker to see that none of the fuses were blown or any machinery went down.

Mr. AYRES. Perhaps I could add one comment in response to your earlier question on private sector education or training.

The incentives, as they exist today, seem to be pretty good for private corporations to train workers to do new tasks if the training involved is perhaps 2 weeks worth of time. Reeducation is something else. It's usually much more intensive and it takes a much longer time and very few corporations are willing to send employees away for 1 or 2 years at their own expense for the simple reason that they're afraid when the employee comes back he's going to move on somewhere else.

Senator BENTSEN. People aren't chattel and we don't own them, and they can take their increased skills with them. That is indeed a major risk employers face.

I see we have a rollcall. That's one of the problems we have in Congress. If we didn't have so much automation, they could send somebody over and we could keep working at this for a while. Maybe I could send that robot over to vote.

My problem is I also have an amendment I'm trying to carry on the floor so I think we will terminate the hearing unless you gentlemen have some other comments that you would like to make at this time.

Mr. AYRES. Well, I do have some up-to-date versions of our earlier estimates on job loss. Perhaps I can give them to you.

Senator BENTSEN. I would like to have those in the record if I may. How lengthy are they?

Mr. AYRES. Three to five minutes.

Senator BENTSEN. Why don't you give them to me now. I would like to have that.

Mr. AYRES. Well, I have to begin by defining the two kinds of robots that we talked about. A level 1 robot in our terminology is a robot that is essentially insensate, that is it has no external sensory capability and it does not react to changes in the external environment. The level 2 robot would have visual or tactile senses.

We used a couple of methodologies. One is a survey and the second one is based on data from the census of machine tools and an analysis of the appropriateness of the robot as the replacement for human operators for each of the various types of machine tools. There are several hundred types of machine tools so you can get a fairly detailed breakdown.

We found on the basis of this that in the metalworking industry, where we have the most detailed information, the level 1 robot, to the best of our information, can replace in principle about 13.6 percent of the existing work force. That is the direct labor, direct manufacturing labor. This agrees with the machine tool analysis which told us that about 16 percent of the machine tools would be amenable to that kind of robotization.

By the same survey methodology, a level 2 robot appears to be capable of displacing about 39.5 percent of the direct manufacturing jobs in the metalworking industry.

Extending those percentages to the whole manufacturing sector gives us the figures 1.3 million roughly as the number of jobs vulnerable to level 1 robots, and 3.8 million jobs are more or less vulnerable to level 2 robots. That does not mean that all of those jobs will actually be displaced nor, I want to add, does it mean it will happen by 1990. I think that part of the Wall Street Journal article you cited was not based on a direct and accurate quotation from me. In fact, I do not think this amount of displacement would occur before the year 2000.

Now one last point. If you assume attrition at 2 percent, then it takes about 5.6 years to attrit the number of jobs that could be vulnerable to level 1 robots in the metalworking industry, and it will take 17 years to attrit the number of jobs that would potentially be displaced by level 2 robots. But that's a very low rate of attrition. If you assume a 4-percent attrition rate, each of those numbers is halved. So it would only take 2.8 years to create the number of openings that level 1 robots could handle and 8.5 years to create the number of openings that level 2 robots could handle.

This is the basis for our saying that on an aggregate national level, the problem should not be too severe. The problem arises from regional concentration.

Senator BENTSEN. Thank you. I'm most appreciative to both of you for coming and for your full testimony for the record.

The subcommittee stands adjourned.

[Whereupon, at 11:05 a.m., the subcommittee adjourned, subject to the call of the Chair.]

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