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ABSTRACT

This collection includes five papers assessing current and projected developments in the field of robotics and the implications of these developments for vocational-technical education. The first paper, "New Applications for Industrial Robots--Perspectives for the Next Five Years" (M. Illi) compares advances in robotics in Japan and the Federal Republic of Germany. In a paper entitled "Extension of Robot Capabilities through Artificial Vision," I. Aleksander compares three generations of artificial vision for robots and discusses the implications of advances in robot vision for future uses of robots. Professor H. H. Rosenbrock explores the relationship between people and machines in his paper "Robots and People in the Workplace." "Social Aspects of the Use of Robots: Implications for Working Conditions and Employment" (R. Schneider) discusses some of the positive and negative effects that robots are likely to have on the workplace. The final paper, "Training and Qualifications Needs" summarizes the conclusions drawn by the authors of the first four papers concerning the training needs of persons working in the field of robotics. (MN)

Robotics developments and future applications

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Robotics development and future applications
Seminar report

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INTRODUCTION

Robotics is a fashionable subject which has caught the public imagination in the past few years. Hundreds of magazine and newspaper articles have been devoted to the subject, and countless seminars and television programmes have been aimed at spreading information and understanding on robotics.

Despite all this activity, or perhaps because of it, robots have acquired an aura of almost science-fiction-like mystery. Robots are dramatic in operation and their anthropoid-like activities immediately make workers aware of their jobplace destruction potential. The threat of job displacement and/or deskilling for many types of employee can form a barrier to the exploitation of the full potential of new technology. Yet these problems must be recognised, and those engaged in devising training and retraining programmes for the introduction of robotics have to find answers that take care of the very important human factors involved in technological innovation, whilst bearing in mind the economic survival of the firm as a long-term objective.

Estimates of the likely increase in the number of robots in use over the next six years, to the end of this decade, vary so enormously that one can only guess what the result will be. The vision and sensors improvements at present being made will, however, almost certainly lead to a rapid spread of robotics applications, affecting a great many assembly line jobs.

An OECD survey puts the 1982 robot population its Member States at 60,000, and estimates that there will be a yearly 30 to 35% increase during the coming ten years.

In the meantime there is a growing trend towards the internationalization of certain types of mass production, of which automobiles and electronics are good examples. It is also in these industries that greater use of robots of a more sophisticated nature will be made, affecting many jobs.

In robotics research, development and manufacturing the trend will almost certainly be towards increasing internationalization partly because of the costs involved, and partly due to an international distribution of expertise which can be brought to the projects. [1)]

All of these considerations make it necessary to ensure a major effort to up-grade skills at all levels, both in manufacturing and using robots, for those firms that use robots of a fairly simple type now will be in a better position to deal with more sophisticated robots later on, as compared to companies that have not had the experience at this stage.

An inadequate response to the education and training challenges posed by the new technologies, resulting in serious shortages of people with robotics manufacturing and applications expertise, could lead to a polarisation of skills, not between workers in a national labour force, but on an international scale, which could have serious, long-term consequences for the European Community.

W. G. MCDERMENT
Project Co-ordinator

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1) For example: The JUPITER R & D Programme for Advanced Robot Technology to be carried out on an international

basis, within the framework of an agreement reached at the Williamsburg Summit Meeting in 1983. Japan is acting as the promoter of the project.

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Dr M. Illi

New applications for industrial robots: perspectives for the next five years

Industrial robots are still a fairly recent innovation. They were first used at roughly the same time as the first microprocessors emerged. Advances in microelectronics, the most obvious example being the microprocessor, enabled the movement of tool-carrying machines to become freely programmable. The spot-welding of the bodywork of cars and the coating of surfaces, with paint, for example, have become classic applications in the last ten years.

There is no limit to the possible future applications of industrial robots. But I do not want to go in for any science fiction in this talk. I would rather concentrate on new areas in which industrial robots will almost certainly be used in large numbers in the next five years. I shall also consider what areas and elements will change in the companies which introduce these new applications.

An assessment of the time it takes to introduce a new application indicates that the only applications to result in the use of robots in fairly large numbers in the next five years will be those on which work is already being done today.

TIME REQUIRED FOR NEW APPLICATIONS

	PHASE	TIME
APPLICATIONS LABORATORY	* DEFINITION * INDIVIDUAL EXPERIMENTS	1 YEAR
	* EXPERIMENTAL PLANT	1 YEAR
FACTORY	* PILOT PLANT * LIMITED PRODUCTION	1 YEAR
	* FULL PRODUCTION	1 YEAR
	TOTAL TIME REQUIRED:	4 YEARS

NEXT FIVE YEARS

* POSSIBLE APPLICATIONS ALREADY IN VIEW
* LIKELY SUCCESS DIFFICULT TO ASSESS

The following tables show probable growth in industrial robots in Europe. It is virtually impossible to give an accurate forecast of the numbers likely to be in use by 1990. However, their relative distribution among the various applications can be predicted with a fair degree of certainty:

APPLICATION FOR INDUSTRIAL ROBOTS

* EQUIPMENT INSTALLED IN EUROPE

1982	9,000
1985	30,000
1990	?

* APPLICATIONS

	Today	1990
WELDING	35%	21%
HANDLING	35%	32%
COATING	15%	5%
ASSEMBLY	10%	35%
OTHER	5%	7%

Almost all the experts confirm what this table predicts: Assembly will be the area of highest growth.

Apart from the type of application, it is interesting to note which sectors of industry use industrial robots in significant numbers:

APPLICATION BY SECTORS OF INDUSTRY IN GERMANY

	TODAY	1985	1990
AUTOMOTIVE	46%	37%	35%
ELECTRICAL/ELECTRONICS	14%	18%	23%
MACHINE TOOLS	12%	13%	13%

COMPARISON OF GERMANY WITH JAPAN

TODAY	GERMANY	JAPAN
AUTOMOTIVE	46%	36%
ELECTRICAL/ELECTRONICS	14%	34%

At present the automotive industry is the only sector in Europe to have fully accepted industrial robots as a manufacturing technology. The electrical and electronics sector is still very hesitant and cautious. I am convinced that this attitude will soon change. The electrical and electronics industry in Japan and my own company, IBM, are already giving clear signs of the likely trend in Europe in the next five years.

AN EXAMPLE FROM THE ELECTRONICS INDUSTRY: IBM

APPLICATIONS - FROM EXPERIMENTAL PLANT TO FULL PRODUCTION

* ASSEMBLY OF PRINTED CIRCUIT BOARDS
* TESTING PRINTED CIRCUIT BOARDS
* ASSEMBLY OF KEYBOARDS
* HANDLING COMPONENTS DURING TESTING
* ASSEMBLY OF MINIATURE GEARING
* ASSEMBLY OF RIBBON CASSETTES
* ASSEMBLY OF CABLE HARNESS
* ASSEMBLY OF ELECTROMECHANICAL COMPONENTS
* FINAL ASSEMBLY OF EQUIPMENT

MAIN ACTIVITY: ASSEMBLY

The largest growth area will thus be assembly. I also expect there to be considerable growth in testing and inspection. This will principally depend on the progress made in the field of visual sensors, in other words, camera and image-processing equipment. Such visual display equipment will be used both on its own in inspection and in conjunction with industrial robots.

As I have already said, the electrical/electronics industry in particular will make increasing use of industrial robots and visual display systems in assembly, testing and inspection. Other focal points will be in the following industries:

* Automotive, including suppliers
* Domestic appliances
* Precision engineering
* Aerospace
* Mechanical engineering

No branch of industry in which components are assembled will be able to escape this trend.

In the second part of my talk I would like to consider the implications the growing use of industrial robots has for a manufacturing company and the requirements that must be satisfied if they are to be used as economically as possible.

Let me begin with a few thoughts on the factors which justify the installation of an industrial robot and the circumstances in which a robot is preferable to other production methods:

REASONS FOR USING INDUSTRIAL ROBOTS IN ASSEMBLY

- COST REDUCTION
  - PERSONNEL
  - STOCKS
  - LONGER DEPRECIATION
- QUALITY
- FLEXIBILITY

INDUSTRIAL ROBOTS
MEAN

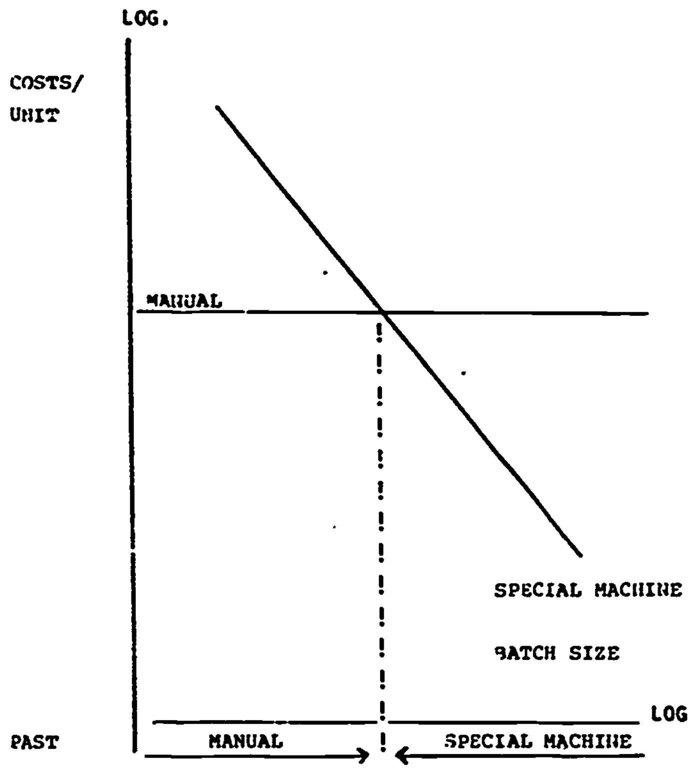
EVOLUTION IN AUTOMATION

EXISTING FORMS OF AUTOMATION: INFLEXIBLE

* CONVEYOR LINE
* NC MACHINES
* SPECIAL MACHINES
* TRANSFER LINES
* AUTOMATIC PROCESSING EQUIPMENT
* ASSEMBLY LINE

INNOVATION DUE TO INDUSTRIAL ROBOTS: FLEXIBILITY

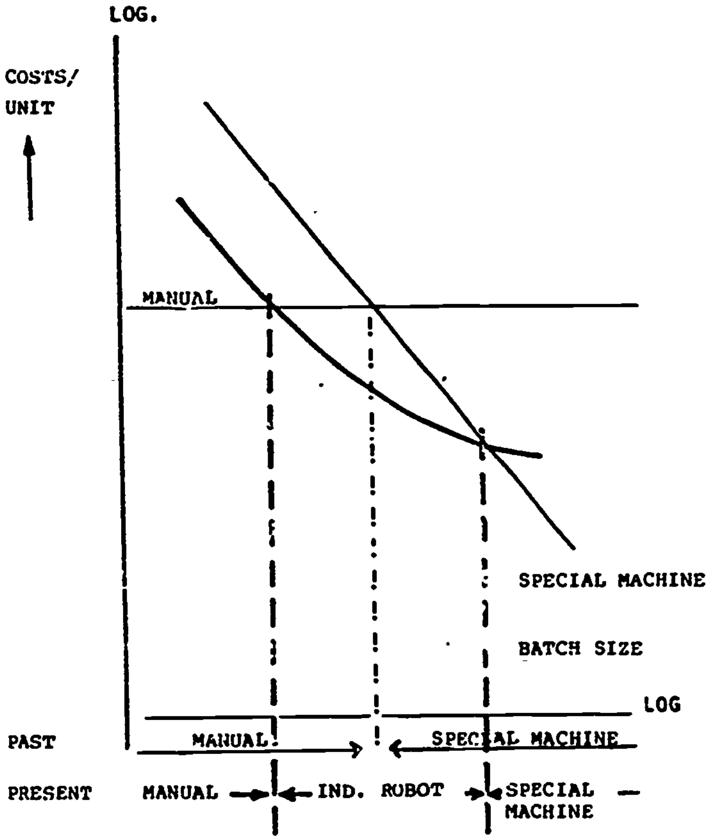
UNIT COSTS AS A FUNCTION OF BATCH SIZE



UNIT COSTS AS A FUNCTION OF BATCH SIZE

NEW: FLEXIBILITY DUE TO INDUSTRIAL ROBOTS

- Short retooling time
- Reusability



Being programmable and flexible, industrial robots have far wider implications for the manufacturing company than, for example, a new type of inflexible machine tool. The changes are likely to be comparable to the effect the introduction of the computer had on administration. The computer not only replaced the old mechanical adding machine It affected activities throughout the company.

In the next few pages I shall discuss the requirements that must be satisfied if full and economical advantage is to be taken of industrial robots - particularly in assembly - and the changes to the structure of the company that will ensue.

REQUIREMENTS IF FULL ADVANTAGE IS TO BE TAKEN OF ROBOTS IN ASSEMBLY

FOUR AREAS:

1. EQUIPMENT
2. PRODUCTS
3. ORGANIZATION OF PRODUCTION
4. ORGANIZATION OF THE COMPANY

ASSEMBLY

1. REQUIREMENTS TO BE MET BY EQUIPMENT

- INDUSTRIAL ROBOTS — 1/3 of costs
  - ACCURACY
  - INTELLIGENCE
    - SENSORS
    - ADAPTABILITY
  - PROGRAMMABILITY
  - COMMUNICATION

- PERIPHERALS — 2/3. of costs
  - ELEMENTS
    - GRIPPERS
    - TRANSPORT OF COMPONENTS
    - INTERLINKING
  - REQUIREMENTS
    - FLEXIBILITY
    - STANDARDIZATION

It is important to note that industrial robots themselves account for only about one third of total job costs. The other two thirds of the total investment are spent on the equipment needed to complete a work station. This is related to the fact that additional equipment is required in assembly and that every assembly task is different and requires its own engineering effort. For these two reasons alone - additional costs and engineering work, for which limited time is available -- the changeover to industrial robots in assembly will be a gradual process.

ASSEMBLY

2. REQUIREMENTS TO BE MET BY PRODUCTS

- DESIGN SUITABLE FOR AUTOMATION
    * FEWER COMPONENTS
    * STANDARD COMPONENTS
    * SNAP CONNECTIONS
    * NO EASILY BENT COMPONENTS
    * STANDARD JOINTING ANGLE
    * Etc.

ASSEMBLY

3. REQUIREMENTS TO BE MET BY THE ORGANIZATION OF PRODUCTION

* EMPLOYEE TRAINING
    - APPLICATIONS ENGINEERING
    - START-UP
    - OPERATION
    - MAINTENANCE
    - REUSE

* PRODUCTION PROCESS
    - INTERLINKING OF INDIVIDUAL STAGES
    - OPTIMIZATION IN TERMS OF:
        - PROCESSING TIME
        - STOCK-KEEPING
        - CAPITAL INPUT
        - QUALITY
        - FLEXIBILITY

ASSEMBLY

4. REQUIREMENTS TO BE MET BY THE ORGANIZATION OF THE COMPANY

- LINKING DESIGN AND PRODUCTION (CAD/CAM INDUSTRIAL ROBOTS)

- LINKING PLANNING, ORDER PROCESSING AND PRODUCTION

- AIM: COMPUTER INTEGRATED MANUFACTURING

The use of industrial robots in assembly will come, but it will be a gradual process. The changeover will require substantial investment, engineering capacity in plant construction and organizational changes. All these factors take time, which guarantees that the transition will be gradual.

Nevertheless, every company and also such public institutions as schools, universities and governments should now be thinking very carefully about initial and continuing training if they are to cope with this transition.

REQUIREMENTS TO BE MET BY INITIAL AND CONTINUING TRAINING

1. FOR REDUNDANT EMPLOYEES

2. FOR WORK ON INDUSTRIAL ROBOTS

   * TASKS

     - DEVELOPMENT
     - PROGRAMMING
     - APPLICATIONS ENGINEERING
     - PLANT CONSTRUCTION
     - OPERATION
     - MAINTENANCE

   * TYPE OF TRAINING

     LINKING MECHANICAL ENGINEERING AND DATA PROCESSING

   * FROM SKILLED WORKER TO GRADUATE ENGINEER

2

Professor I. Aleksander

Extension of robot capabilities through artificial vision: a look into the future

EXTENSION OF ROBOT CAPABILITIES THROUGH ARTIFICIAL VISION; A LOOK INTO THE FUTURE.

1. INTRODUCTION

It could be said that 90% of robot usage in industry is currently on what one might call "open loop". This means that robot manipulator arms go about their pre-programmed routines with virtually no feedback from the environment in which they operate.

This way of thinking has had an immense effect on the potentials and limitations of what can be achieved in manufacturing industries through the use of industrial robots. One often hears of redesigning products so that they could be assembled by robots. In most cases this means that parts are manufactured to include their own guiding channels to compensate for the placement inaccuracy that one finds in current robot arms. A human operator while performing an assembly task (or almost any other production task) makes a very heavy use of sensory feedback in performing his task. In most cases 90% of that sensory feedback comes from his ability to use his eyes. Clearly this is not always true. Think of the insertion of a screw into a threaded hole. Much of the feedback in this sort of situation is sensory. Therefore, although the word vision is heavily used in this paper, the techniques proposed include other forms of sensory feedback. After all, in most cases it is merely a question of choosing the appropriate transducer. The demands on the intelligent processing of such information whether it be tactile or visual are very similar.

Many have argued that the development of robotics and flexible manufacturing systems can proceed without the need to think of artificial vision, or indeed, artificial intelligence. Much of their argument has resulted from the fact that current vision systems and scene analysis programmes have proved to be impractical in realistic situations. For example, many vision systems will not operate in dirty environments or in situations where the lighting is not perfect. In artificial intelligence too, only systems that operate in highly simplified worlds have been demonstrated over the past few years. The central point of this paper is that the situation has changed very rapidly and that the poor demonstrations of the past are not indicative of the possibilities of the future. The outstanding single factor that has brought this change about is a remarkable fall in the cost of electronic equipment. This means that redundancy techniques and parallelism can be used in order to make the operation of vision systems much more sophisticated, bringing about an expectation of operation in real time within most manufacturing complexes and keep the processing costs for all this at the level of a small fraction of the costs of mechanical hardware.

This paper will be divided into three further parts. The first part will discuss the changes that are being brought about by currently available vision systems. We call these the first generation systems. The second part of the paper, on second generation vision systems describes work that has recently emerged from research laboratories (such as the author's group at Brunel University). Such work is characterized by the fact that the machinery is adaptive and removes the need for pre-programming every time a new problem is encountered. This pre-programming characteristic is one of the drawbacks of generation-one systems.

The third part of the paper will take a look into the future where the prospects for work being done in artificial intelligence laboratories being applied in robotics are investigated. In addition to the lack of pre-programming of generation-two systems, these generation-three systems would have the ability to communicate with untrained users in simple natural language.

In all three parts of this paper, particular attention will be given to the man-machine interface and the responsibilities that operators operating such machinery will be required to undertake. Clearly the skills of such operators will come under scrutiny.

2. FIRST GENERATION VISION: GEOMETRICAL TECHNIQUES

As stated in the introduction, the primary objective of robot vision is to allow the robot programme to branch (that is deviate from a single path) depending on what is seen by the robot eye. Without vision the robot arm may be expected to repeat the same programme over and over again. For example, it might inspect a certain object in some operation (e.g. assembly). Two immediate applications for vision become apparent. We can now imagine that objects are being delivered at the pick up point which is surveyed by means of the television camera. The first application would require the vision system to decode the shape of the object so as to issue a different instruction to the robot programme every time a different object is presented. Say that there are three objects that the robot must concern itself with, there could be three different things that the robot could do, each initiated by one of the objects.

The second obvious application is that having arrived into the work area, the object needs not be as accurately placed as might be the case where there is no vision. The vision system could be asked to detect not only the position of the object but also its orientation. This information may be used to send appropriate instructions to the robot programme which brings the gripper down into the work area to meet the piece part in the right way.

Further applications of vision which may or may not involve a robot arm is the question of quality control. Items could move past a viewing space either on a conveyor belt or as part of some other transport system. The vision operator may be used in a range of ways. On the one hand it could be looking for blemishes in the surfaces of things while at the other extreme, it could be looking for incomplete assemblies. The important factor in such applications is the detection of special features in what is being seen which may require some simple action from the mechanical part of the system such as the removal of a piece part from the production line or the marking of the piece part to indicate that human inspection is required.

We define a "generation 1" vision system as being typical of those that are manufactured and sold at the present time. In the main, these systems have four salient parts; the input transducer, a frame store, a feature extractor and a classifier section.

The most inexpensive input transducer on the market is currently a television camera. In this paper we will often refer to costs. The way this is done is by referring to the fraction of the cost of a medium sized manipulator arm. Typical of such an arm may be the largest device in the Unimation Puma series. A black and white television camera would therefore, cost approximately 0.003R units (clearly a Puma 500 would cost 1R unit, R standing for robot). Such a camera would be quite capable of delivering an image which after digitisation would consist of a matrix of 256 x 256 picture points each capable of representing 256 levels of grey. In technical jargon each such picture point is known as an 8-bit pixel.

At the more expensive end of the television camera range, one finds cameras which provide colour information and are capable of a resolution of 512 x 512 pixels. Clearly, in this case each pixel may be thought of as containing three times the amount of information to take care of the three primary colours. These more sophisticated cameras would cost in the region of 0.01R units. Given the above figures it is easy to calculate the precision with which work using such cameras can be carried out. First it is clear that a 512 x 512 image, say, will allow a piece part's position to be calculated to one part in 512 on a linear measurement. Secondly, standard television cameras produce one full frame in 1/25th of a second or a 1/2 resolution frame in 1/50th of a second.

One can also purchase solid state cameras which can be driven at higher speeds but these tend to be in the experimental stage (generally, manufactured using chargecoupled solid state devices). These faster cameras are likely to cost in the region of 0.03 to 0.05R units.

As the name implies, the framestore stores a single frame of television camera output. This is generally achieved with very fast random access memory devices to which and from which access is controlled from a fast, dedicated, micro-processor chip. For example, for a 256 x 256, 8-bit-per-pixel system, 256 kilobytes of memory are required. In special-purpose hardware this usually does not create addressing problems because such a store is addressed sequentially as the information from the camera comes in on the video line. Most of the operations within the vision system are carried out by programmes situated in the micro-processor which examine the pixels stored in the framestore. This generally, requires a great deal of processing as this information might have to be accessed two or three times in order to provide the necessary answers. It may be clearer to see what the system is doing if we consider the next part; the feature extractor.

The feature extractor is in fact a program. In most vision systems this device extracts some simple geometrical properties of the image held in the framestore. For example, one can easily envisage the processing that needs to be done if say the area of an object is to be calculated. The processor simply sets in motion a sequential scan of all the storage locations in the framestore and counts those that have a content which falls below a certain intensity threshold. Similarly it is easy to see how the system might produce a statement of the perimeter of an object and indeed provide areas and perimeters of holes, perhaps, that may be found within the object.

Additional pre-programmed features that such systems extract are the positions of the centre of area of objects and holes within them and the major radii of such objects. A typical vision system will provide something like forty features of the kind mentioned above. Unfortunately, as can be imaged from the description of the system and the amount of data that has to be scanned in order to extract these features, it is easily seen that the extraction of these features can take a considerable amount of computing time. This is true even when the programming of the micro-processor is done at its most efficient level. Typically, it could take a system between one and five seconds to produce forty feature vectors. This places severe restrictions on the speed with which objects can be presented to the system. Generally, this is not much of a problem if objects are viewed in a work position where a piece part is delivered every five or six seconds. On conveyor-belt systems, however, speeds are usually much higher and an average industrial working standard is about 4 piece parts.per second.

There are framestores which in addition to feature extraction can perform what are known as image pre-processing tasks for example, cameras usually produce arbitrary signals (noise). Some pre-processing schemes exist which get rid of this noise before the feature extractor gets to work on the image. Similarly, pre-processing can find the edges of an object and smooth out ragged edges before the features are extracted.

The fourth part of the system, the classifier, has the duty of turning the collection of features into a control signal which will eventually drive the robot. In this action the general principal is followed that the operator of the system will define such an action. All that the computer does is to associate the actions with the feature patterns. This procedure relys heavily on the fact that two objects, or one object in a different position, or an object in a different orientation, will generate a substantially different set of features so that a substantially different action may be associated with these patterns.

Currently marketed vision systems range in price between 0.3R units and 1.0R units. The first disadvantage can easily be seen; these devices are slow and expensive. However, with advancing technology one would imagine that both the cost would come down and the speed of these systems would go up. So speed/cost performance is not their worst disadvantage: there is worse to come.

First, in order for the feature extractor to work without making enourmous demands on the pre-processing, the images seen by the system must be clean and well lit. Second, the system would be unable to cope with textured objects. Thirdly, a tremendous amount of computation would have to be done in order to pre-process out object images if objects overlap. Methods for dealing with overlapping objects are being studied in several research institutes. However, at the present time they appear to require the long computation times. The third difficulty appears if one tries to apply such systems to quality control, particularly in the recognition of missing parts in a complex scene. Imagine trying to detect a missing cogwheel in an image taken of the innards of a clock by using the geometrical properties of the image only. Such schemes have been attempted but they generally require many man-years of programming by an expert consultant in order to solve a particular problem. If the problem changes even slightly the programs have to be rewritten, therefore, the entire operation is totally unavailable both to the operator and the production engineer. It is clear to see why the managers of many robotics installations are currently shunning vision systems. They may well be more of a nuisance than a help.

3. SECOND GENERATION VISION SYSTEMS: THE ADDITION OF ADAPTABILITY

Second generation systems are being designed to overcome two of the major limitations of first generation devices: a reliance on well defined geometrical features and the need for devising special programmes for inspection problems. It should be made clear that these devices will not replace all the useful facilities that are available in first generation systems. In fact, it is likely that they will contain geometrical feature extraction facilities while at the same time providing ways of by-passing them. We shall first consider how they work and second what sort of a difference a user might experience in moving from a first to a second generation vision system.

Notionally an adaptive system treats the entire image as just one enormous vector of bits. It does not, except in exceptional circumstances, make use of any geometrical information regarding the relative positions of the pixels in the image. In fact, the first processing task in an adaptive system is to take the vector of bits as it comes from a camera's scanner and remap it in a fixed but arbitrary manner onto another vector of equal size but such that adjacent bits no longer come from adjacent pixels or from within one individual pixel.

This randomised vector is broken up into groups containing n bits each. Conceptually one can imagine these groups each addressing a storage element containing 2^n bits of storage. Again conceptually, one can imagine that very many storage elements of this kind are being addressed simultaneously. This would give the system an enormous speed in the sense that if it were totally parallel it could give a decision on an image in the time that it takes to access a storage element.

With current technology this could mean the classification of a possible ten million images per second. Now, no imaginable transducer can deliver images at that rate. Therefore, currently designed systems do not operate totally in parallel but are designed in a semi-parallel fashion so as to comfortably be able to deal with 25 images per second.

Let us consider how much memory is implied by these sorts of systems. Assume that the image consists of 512 x 512, 8-bit pixels. This indeed is a total of 2 million bits in the input vector. A typical value of n is 8. Indeed, in the laboratories of Brunel University it has been shown that very rarely does one need to find a value of n greater than 8. The effect of this value on performance will be discussed later. Therefore, each individually addressed storage element with 8 address terminals would require $2^8 = 256$ bits. Doing the sums it turns out that the total storage then becomes 8 Megabytes. This amount of storage (that is the full cover of one image with a relative value of n) is called one discriminator. Therefore, at current technological values of storage a system costing as much as a first generation vision device (i.e. 1R) could contain four or five such discriminators.

Two factors need to be noted, 1) is that a worst case value of n was chosen and 2) that the cost of storage is continually falling. The way these architectures are built up is that one can trade off the number of discriminators against the value of n. The relationship is such that as n is decreased by 1, the number of available discriminators may be doubled. The significance of having more than one discriminator in the system is that as we shall see in a moment, each discriminator is dedicated to one recognition class, so that the more discriminators there are the more different things can be recognized. Therefore, if a system with the dimensions outlined above were built, and if a value of n of 4 were selected instead of 8, as many as 80 discriminators could be made available for the same amount of equipment.

Before considering the effect of the value then, let us look at the way in which the system would be used. First the operator would press a key on his key pad to indicate to the system how many classes of decision, that is number of different branches of his programme he desires. He would then simply drive his robot in the usual way, once for each of these classes at least, with an example of the desired object in view of the vision system. It is more than likely that if the same branch has to occur for say an object in different orientations, these different orientations would have to be shown to the system as belonging to the same class. One of the main features of this type of machinery is that it generalizes from the objects that have been seen during the above training procedure. This means that if a new object is presented not exactly in the same position or not exactly in the same orientation, it will still take the correct branch.

The system is very good interpolating between trained examples but should not be expected to extrapolate. For example, if shown the front of a gadget it should not be expected to recognise its back.

It is clear that the value of n is a vital perameter in the operation of these systems. The effect of changing n will now be described as well as a way in which the system may be asked to vary the value of n automatically. Very simply, the value of n can be seen as a descrimination index for the system. For example, if two images that are very similar but need to lead to different branches of the control program, then a high value of n is required. However, to give some example of scale, experiments carried out with the WISARD system at Brunel (see Reference) on seeing whether a change of expression in a person's face could bring about the branching of a programme. This is quite a subtle change in the image being seen and it was discovered that a value of n = 8 was sufficient. On the other hand where a great deal of latitude is required from the system, for example, if branching is required as a result of very broad categories such as an object being on the left of the picture or an object being on the right of the picture, a low value of n is required.

In order to illustrate the operation of such a system, we shall look in some detail at the interaction that a human operator might have with it since the beginning of an operation. Assume that the task in hand is that of sorting into boxes the piece-parts of (say) toy motor cars. Because of the need to save casting space and time, one casting operation produces ten parts that belong to two different toys. After fettling and deburring, the parts fall down a chute into an angular jig that is in the field of view of the vision system and from which the robot can pick up the parts with its gripper.

The problem for the robot arm is to pick the piece parts out of the jig and place them on to one of two pallets (one for each toy) in a predetermined position and the right way up. Two requirements become immediately obvious to the production engineer. First, he will be asking the robot to perform one of twenty possible programme branches depending on what is being seen by the vision system. This number could be much greater should the robot be required to place the piece parts on pallets in a particular orientation. At the moment it has been assumed that the robot merely needs to decide whether to turn the piece part around or not, which results in two possible operations for each class of piece part. Secondly, the production engineer notices that a second generation system is required as the turning or non-turning branching must be done on the basis of texture information. That is the piece parts cannot be backlit as one would not be able to tell whether they were upside-down or not.

The production engineer would then issue a training schedule for the operator. As most of the parts are approximately rectangular, they can fall into the jib in one of eight ways (given appropriate jig design). He would therefore instruct the operator to carry out eighty training operations.

A bit of sophistication immediately suggests itself. It is quite possible to think of a system where the robot arm itself could do its own training. This would merely require that, starting with the ten piece parts in known positions and orientations, the robot were programmed to drop them into the jig in a pre-determined fashion. That is this particular program would only have one branch and would therefore not require vision. This would greatly reduce the operator involvement.

Whatever the case, at the end of the training period it is suggested that the system should merely store the images seen and the actions required from them. From this position onwards it can devolve its own optimal training information for the n-tuples.

The major actions of the robot arms are, 1) pick up from a known place, 2) turn over or not depending on visual information, 3) place in one of ten possible positions. The manufacturer of the vision system would have included an automatic training program in the system which would have the following intelligence. First, it would only concern itself with those actions that branch on a visual input. Second, it would evoke different sets of discriminators for each of the different actions required. In this example, it would evoke two discriminators to trigger off action 2) while it would call on ten discriminators to trigger off action 3). A less intelligent system would simply demand twenty discriminators to cover the twenty actions. The system would then proceed to use the labelled training data and perform successive training runs, each time varying the value of n. It would be able to evaluate its own results and select a value of n which gave sufficient discrimination on the training database, allowing a safety factor for variations in data outside of the training database.

Because this automatic training can happen at machine speeds, it could be done very rapidly indeed, requiring no more than a few minutes of machine time. At the end of the procedure the machine would report that it was ready, whether it had any spare capacity in its n-tuple store or not, or perhaps if it had run out of local storage, it would report that the job cannot be done. In a properly designed system the latter event would be expected to be very rare.

In summary, therefore, a second generation vision system has removed the specific need for pre-programming almost completely. The operator and the production engineer both having an understanding of the limitations of the system can communicate with each other and set down tasks for the system at the level of what is being seen and what actions are required from the robot. What is being seen is simply shown to the vision system while the actions are derived through operator drive as is done with blind systems at the moment. It is felt that the training implications for production engineers and operators as implied by this sort of system are not severe. However, they require a well thought through programme of simplifying the mental image of what the system is doing. It is felt that rather than try and explain the technicalities of storage and programming, it may be useful to endow these more intelligent vision systems with almost human properties. For example, the operator must be able to report back to the production engineer say, that the machine simply can't "think that fast". Or he might say it needs to see "more examples", and so on. This type of approach is somewhat novel and would need to be studied by educators and robot scientists together.

4. THIRD GENERATION VISION SYSTEMS; THE INFLUENCE OF ARTIFICIAL INTELLIGENCE

The major limitation of the systems discussed so far has been the highly restricted channel of communication between the operator and the machine. The logical sequence we have discussed so far has been one of banishing the concept of programming in a computer language as far as the operator is concerned. However, the result of this has been that the operator has been delegated to communicating only very simple notions and ideas to the system through a limited key pad. Artificially intelligent systems would allow the operator to communicate with it in natural language, albeit within the restricted world of the task in hand. This, indeed, has been the stated aim of workers in artificial intelligence for more than ten years. The results in this area have not been impressive and one is therefore still looking to the future for the creation of practical working systems. In this section we shall examine some of the work that has been done in this area, mainly in order to predict where useful advances might take place and the sort of constraints that such systems might place on the user.

The scenario developed in the early seventies by Artificial Intelligence workers such as Terry Winograd at M.I.T. was essentially a robotic one. It was structured with three major elements. The first was a simplified environment containing simple objects such as pyramids, boxes, spheres, etc. The second was a robot arm controlled by an intelligent program, while the third was a human operator. The human operator would give orders or ask questions of the system in natural language or near-natural language. The intelligent program in the system was such that first it could recognize the environment through a process of pattern recognition (which, by the way, was not elaborated by the M.I.T. team). The intelligent program was therefore, totally knowledgeable about the position of all the objects in the field, their attributes such as size, colour, shape, etc. and their orientation. This knowledge would be represented in the system as a data base with different fields for each of the possible attributes, such as colour, shape, position, etc. Through a process of parsing the human input, the system could act on statements such as; "pick up the green box". The action would be one of understanding directly the command "pick up" and carrying out a search through the data base for objects that have green and box in their respective data base fields. Were the search to discover that there were several objects that fitted the description,it would call on and output the pre-stored message "which one?". If only one appropriate object was found, it would use the information in that object field (such as position and orientation) in order to instruct the robot arm to carry out the picking up action.

This, however, was only part of the duty of the intelligent program. It was envisaged that the robot might have much more complicated tasks to carry out than just picking something up and putting it down. For example, it might be asked to start with a heap of bricks and build an archway. It was this problem which captured the imagination of Artificial Intelligence workers and led to a great deal of work on "problem solving" by computer. Indeed, probably the most important work to come out of M.I.T. is the SHRDLU problem solving system, or the STRIPS scheme evolved by Nils Nillsson at the Stanford Research Institute.

One can identify several reasons as to why this sort of work has not found its way into practice. The first and rather obvious one that the labelling process as described would require a second generation vision system as a front-end in order to do the job. Therefore, it may be that some of the work done in the United States in this field will prove to be useful once second generation vision systems become common place. The second difficulty is a little more technical, but nevertheless pertinent. Because second generation vision equipment was not in evidence at the time that most of the work in Artificial Intelligence was being developed, a great deal of effort went into studies of data base structures which in the face of second generation vision systems would appear to be inappropriate. These data base structures in a real-world situation would contain an enormous amount of detail relating to the features of the object under scrutiny. A great deal of the effort aimed at improving the speed of searches of such data bases and allowing the system to make approximations. Given a good second generation front-end, such time consuming and memory consuming data base activities are unnecesary.

Further main criticism that one can make of artificial intelligence systems work is that the scenario in which a robot is set loose amongst the large number of objects and solves problems set to it by the operator is not one that could be recognized as having any industrial realism. This sort of problem is derived much more from the American space programme where it was envisaged that the robot could be put on a distant planet where it would be instructed by a human controller back at base in near natural language. The robot would then need to solve problems that would arise as a result of needing to satisfy his human instructor. The following example may clarify the difference between the abilities of SHRDLU as apposed to those required of a third generation vision system.

A typical SHRDLU conversation might go something like this:

Operator:	"Pick up the green pyramid and put in the white box"
SHRDLU:	"OK"
User:	"Now put the lid on the box"
SHRDLU:	"I take it that you mean the white box, I can't decide which lid, please help me"
User:	"The white lid please"
SHRDLU:	"OK"
etc. etc.	

On the other hand, a conversation with a third generation vision system may go something like this:

User:	"This is the box of split washers"
System:	"Thank you, I have taken that in"
User:	"Are you capable of picking up one washer out of this box at any one time?"
System:	"Yes"
User:	(Placing the box in the top left part of the field of view of the vision system) "This is the position of the box for the next operation"
System:	"I understand"
User:	(Causing an engine casing to appear in the lower half of the field of view of the system) "This is where the centre of the washer must be placed" (The user points to the position with a pencil. Clearly a cursor on a visual display unit might have been used but the possibility of not doing this is interesting).
System:	"Please look at the position I am indicating on the screen for where I have understood the washer must go. Is this OK?"

User: "OK" Now please carry out one assembly operation"

System: "OK" (Carries out the placement of a washer in its position)

User: "Take a high resolution look at the area where the washer has been placed and raise an alarm should the image be different after a subsequent assembly operation"

System: "OK"

It is seen that a highly integrated approach is implied here, where the language-understanding system has deep "knowledge" and control of the front-end vision system. Such development of integration is of current concern in several research laboratories but it will probably be several years before prototypes become to be demonstrated, and probably a decade before such systems will be engineered for industrial environments. This assumes that while the knowledge processing is studied, voice input and output will undergo a fair deal of technological development.

5. THE EFFECT OF VISION ON FUTURE USES OF ROBOTS

Here we stand away a little from the technical detail of what has been discussed and try to assess the spread of robot technology in the productive industry as well as the implications that this might have in terms of the training of personnel and the structure of organisations. The major effects of vision may be summarised as first being able to do current robotics tasks more effectively. An example of this is the use of vision in assembly tasks where the costs of mechanical retooling. would be offset by the potentially low cost of electronic vision. Secondly, the use of robots will spread within industries that already have robots but on new applications. A typical case of this is the vast field of quality control which could either be incorporated as part of current pick-and-place operations, or could lead to the use of robots in parts of the factory where the pick-and-place operation was being introduced for the purpose of quality control alone. Thirdly, vision will take robots into industries where they are currently not considered at all. An interesting example of this are agricultural organizations where they are considering the introduction of robotics for applications such as fruit and vegetable harvesting as well as the quality control operations that may be associated with these activities. Other examples may be the clothing industry, shoe manufacturers, etc., etc. Most of these are selected because of their dependence on the visual appearance of their product. The quality control aspects also make robotics more attractive to most of the packaging industry where a visual inspection of whether a package has been properly put together or indeed, whether the printing on the package is appropriate, is of high concern.

With this scenario in mind, there are some obvious effects that are likely to influence the manpower requirements over the next ten years. There is no doubt that possible successes in vision will lead to an eventual decrease of work forces in many industries. The impact will begin to be felt with the deployment of the second generation schemes discussed above. It is unlikely that the first generation systems are going to have much effect. Therefore, in some sense there is a period of about three years during which industry can prepare for these changes. Clearly the best policy would be to formulate a plan which looks forward much further than that,at least to a ten year span.

Having said above that there is likely to be a reduction in the size of workforces, the reasons for this should be closely investigated. It is unlikely that the reduction will occur in organizations where robotic devices are already being used, indeed, with the spread of robotics the demand for semi-skilled manpower to work alongside the robots is likely to increase. After all, in such situations the addition of a robot to a factory can be seen just as the purchase of new and more sophisticated tooling. It is in areas such as quality control where, as part of the cost reduction attributable to vision, there may be a loss of unskilled inspectors. This kind of situation, however, provides an opportunity for balancing out the possibility of increased productivity and the consequent increase of skilled and semi-skilled workforces against the possible shortfall in unskilled labour. This is not an uncommon situation in automation and in past successful developments it has always been patently obvious that the key issue is appropriate education.

Educational enterprise in this area must rest on the notion that semi-skilled work of a high degree of responsibility in a factory automated by means of robots and vision, should be accessible to most. The thrust of educational programmes should be aimed at both breaking down fears and increasing skills in robot use and raising awareness of the continuous advances that one is likely to see in this type of technology. It will be important to put across the notion that such advances will improve the interaction between man and machine rather than generate machines which are more and more bewildering to their users. In the most ideal of worlds, the semi-skilled worker should constitute a major force in bringing about such improvements. Sensitivity to this point at the educational level may be the key to a successful exploitation of the advancing technology.

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Professor H.H. Rosenbrock
Robots and people in the workplace

ROBOTS AND PEOPLE IN THE WORKPLACE [1)]

Almost without exception, the robots in use today have not way of sensing the world around them. They can do what they have been instructed to do, but they cannot spontaneously change what they are doing if circumstances change. Robots with an elementary sense of sight and touch are being developed, and a few have found their way into use. But the ordinary, present-day robot is blind and deaf and without any sense of touch.

If this makes the robot seem primitive and limited, that is certainly a part of the truth. Yet it is not the most important part: The robot has inside it a computer which gives it, within its limitations, a remarkable flexibility. The program in the computer can be changed almost instantaneously, so that a robot which has been doing one job can be switched rapidly to do another. Let us look at some of the uses of robots in industry.

The most widespread use is for spot-welding in the motor industry. A car body is constructed from a number of pressed steel parts: Floor, sides, roof, wings, etc. These are joined together, for the most part, by spot welding. A spot-welding gun, like a pair of tongs, has two copper electrodes fixed to it. These are clamped to either side of the metal parts which are to be joined. Then a heavy current is passed between the electrodes, so that a small circular area in the sheets of metal is made red hot almost instantly, while the pressure of the electrodes causes the two layers to fuse together.

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1) This paper is based on the Fourth Hartley Lecture given by Professor H. H. Rosenbrock to:
The Royal Society
The Institution of Chemical Engineers
The Institute of Measurement and Control

Something over a thousand spot welds are needed to construct the body of a car.

This job was done at first by men. The heavy welding guns were hung on wires from spring-loaded reels overhead, so that the operator did not have to support the weight. though he had to manoeuvre the gun. The work has strenuous, and it had to be done with considerable accuracy, and under pressure of time from the moving conveyor belt that carried the cars.

In any modern car plant, this job is done mainly by robots. There will probably be twenty to forty of them, in groups of four. As each car body arrives, they swing around from their rest position, and each of them puts in some of the necessary welds.

Robots, of course, are not the only machines which can be used for this job. Large, special-purpose machines can be built to do it, but if the design of the car is changed substantially, the machine has to be redesigned and re-built. The advantage of the robot is its flexibility. Changing the design of the car will require some changes in welding guns, etc., but the same robots can be used. All that is needed is to change the program in their computer.

Indeed, this can be done so quickly that different models of a car can often be mixed on the same assembly line: For example two-door and four-door versions. One way is to tag each body with an identification which can be read by an optical device beside the line. Then as each body arrives it is identified, and the appropriate program is used in the robot's computer. When we say that present-day robots are without sight, therefore, this is true in a general sense, but also needs qualification. The optical sensor which reads the tag on a car body is acting as a remote eye for the robot. It can only do one thing, namely reading tags, but that is all that is required for the job that the robot is doing.

From this and from similar pictures, it is usual to draw a number of encouraging conclusions. Productivity is increased, because more cars are produced by a given amount of labour. Since on average we can each consume only as much as we produce, it follows that we are all on average richer. The enterprise using robots will become more competitive, and will grow to provide more jobs. The work that was replaced by the robots was strenuous, demanding, repetitive and dull. Robots do it not only more cheaply, but also with greater accuracy and consistency.

There is certainly an element of truth in this view, but it is not the whole truth. What I shall be concerned with, in fact, is to set this picture in a wider framework; but before doing so, let me give some further examples of the use of industrial robots.

In spot welding, the robot has only to go from one point to another, and the details of the path it follows, within limits, are not important. It is therefore programmed by use of a "teaching pendant", a small box with a number of push buttons, at the end of a cable. Each button activates one of the robot's joints, and the operator can therefore "teach" the robot what to do by pressing the appropriate buttons. This programs the computer in the robot, which can then repeat the operations indefinitely.

Paint spraying is another use of robots which is likely to increase rapidly in the future. Here, the path of the spray gun attached to the robot, and the speed of movement, must be accurately specified. The usual way to do this is to disconnect the drive to the robot, and have the operator spray the part.

The computer in the robot records the path which is followed, the direction in which the gun is pointing, and the points at which the spray is operated. Then again, it can replicate these actions indefinitely.

The point to be noticed is that it would be excessively difficult to program the computer for such a task in the way which is used for mathematical or commercial programming: That is, by writing a series of instructions for the computer. In the first place, this would require a detailed theoretical understanding of the necessary movements of the spray gun. Then it would need a capacity in the programmer for three-dimensional visualisation. It would also need a highly-developed programming language to ease his task. On the other hand, a skilled operator has no difficulty in carrying out the necessary movements, and they can then be incorporated into the memory of the robot's computer. In a very real sense, the skill of the operator has been captured by the robot.

As I was told in the United States, the incentive to use robots for painting cars arose largely from the unsatisfactory conditions under which operators had to work. Environmental legislation was forcing manufacturers to use water-based, rather than solvent-based, paints. These had to be applied in conditions of high temperature and high humidity, which were unsuitable for workers. Similar considerations applied to the spraying of underseal in a European plant which I visited. The underseal was a thick plastic compound, and even in a well-designed spray tunnel the conditions were unpleasant. Spraying, too, was overhead, and consequently tiring. The operators had therefore been replaced by robots which replicated their movements as the cars passed overhead.

In some cases the work taken over by the robot is dangerous as well as unpleasant - for example the manipulation of red-hot metal in a forging press. In other cases it is the routine repetitive nature of the work which makes it unattractive.

There is no lack of such examples, and it would be easy to continue in this vein. The common theme is that robots can relieve us from work which is in some way unsatisfactory or undesirable for human beings. This may be because it is dirty, or dangerous, or unduly strenuous, or simply repetitive, boring and dull.

The question I should like to pose at this point, is: Why is there so much unsatisfactory work being done by men and women? Work of such a nature that the best thing we can think to do with it is to have it performed by robots. Is it in the nature of work that it is inevitably undesirable? Or is there some other explanation for the preponderance of work which seems so ill-fitted for human beings?

There is, after all, an extreme discrepancy between the ability of a robot and even the most limited human ability. Some of the tasks which I have described being performed by robots can impress us by the apparent ability which the robot displays: For example, the deburring of gearboxes. But the skill is simply a human skill, captured in the robot's computer. What the robot can do is to repeat the action over and over again, all day long and every day. This was previously the human task, and such intense, incessant repetition of a simple sequence of movements is surely an under-use and mis-use of the abilities of men and women.

Let me here make some distinctions and qualifications. Where work is unavoidably dangerous, or excessively noisy, or dirty, or strenuous to a point where it imposes severe stress, then there is a clear gain in relieving men and women from the need to perform it. My question is directed towards work which is unsatisfactory because it uses only a trivial part of human ability. One sees a multitude of examples of such work in all industrialized countries: Work which involves no skill or judgement or control, but only the repetition of the same movement, over and over again, at an interval perhaps of only a few secconds.

This, I think it has to be admitted, is a modern development. If one talks of skill in general, there can be a question whether it has increased or decreased. For every example of an old skill destroyed - of the wheelwright or blacksmith or carpenter - one can quote a new skill created - of computer programmer, maintenance technician or shorthand-typist.

If, on the other hand, one looks at the proportion of the population which works continuously at repetitive, mechanical, trivial tasks, then this seems undoubtedly to have increased quite sharply in the past one hundred and fifty years. In earlier times, most people were engaged in agriculture, with a multitude of tasks, and a variety enforced by the seasons. Most goods were made by craftsmen, without extreme specialization. To find examples of unremitting, trivialised, repetitive work, one has to look to the use of men simply as sources of power: The galley slave, or the Roman slaves who walked the treadmills in the Spanish mines to keep them free of water. Or one has to look to the nailers or pin-makers of the 18th century, who were the precursors of the industrial revolution.

The way in which trivialised, repetitive tasks were created and multiplied by the industrial Revolution is clear and widely known. There was a threefold process of mechanization, automation and subdivision of work, each of which fed upon and reinforced the others. Mechanization incorporated human judgement. The subdivision of work resulted from each of these, and in turn made each of them easier.

The skill of the cotton-spinner, for example, was built into the "self-acting mule" in 1830. Fragments of his job remained, such as mending broken threads, removing spun thread or cleaning the machines. The skill of the hand-turner was largely incorporated in the slide rest, and then in the automatic lathe. The fragmentary jobs created by this continuing process remained to be done by men and women, unless by a further process they too could be automated.

What we are seeing are the final stages in this long, slow development. In the course of years, a vast range of trivial, repetitive jobs has been created, and the robot finally allows us, in many cases, to complete this process. The engineer's answer to unsatisfactory work is a simple one: Automate the jobs out of existence. Looking at this final stage, it is possible to see it as entirely beneficial.

What this view ignores is the preceding development in which jobs were fragmented and trivialised. It is only necessary to go a little way further back, from the ultimate stage where no human work is left, to see a less encouraging picture. There is, for example, a robot carrying out continuous arc welding. The work is held in a jig on the rotating table, and the robot puts in the weld. Meanwhile the operator removes the welded part and mounts a fresh workpiece in the jig. When the robot has finished, it withdraws and the table is swung around, and the whole cycle begins again.

Previously, no doubt, the welder did the whole job, mounting the part in the jig, welding it and removing it. There might be some problems with heat and fumes from the welding though these could be overcome by suitable ventilation. Otherwise, the welding demanded a certain degree of skill, perhaps not very high, but certainly higher than is needed to mount and remove parts from the jig.

If one had asked the welder, before the robot was introduced, which part of his job was most satisfying, he might well have said, the welding. Yet this has been given to the robot, and the job of the operator has now become totally unskilled, and more fragmented and trivial than before, as well as being paced by the machine.

The example is a simple one, and not very important is itself, but it illustrates well enough the flaw in the engineer's solution of abolishing jobs that are unsatisfactory. Before jobs can be taken over completely by a robot, or any other machine, they must first have been fragmented and deskilled. It is rare for any job requiring a distinct human skill to be taken over completely and entirely in one stage by a machine. This is almost always done bit by bit, and at each stage the job left for men and women are whatever remains over, when the job of the machine has been determined. In order to apply the cure, to abolish the trivialised job, one first has to create the disease, the supply of trivialised jobs which can be done by robots.

In this respect, the robot is not unique. It merely stands as a type and example of the changes which microelectronics and the computer will bring in the next twenty years. We shall be able, with their aid, to carry on rapidly the process of breaking jobs into their fragments, and performing some of these fragments by machine, leaving other fragments to be done by men and women. We shall be able to do this, not only for manual work, where it has also been done in the past by other means, but for clerical and professional jobs where it has been hardly possible. Clerical work is already being affected by the computer and the word processor, and the electronic office can carry the process further. Computer-aided design is at the beginning of a long development which can incorporate into the computer large parts of the designer's and draughtsman's jobs, leaving other fragments still to be performed for a time by human beings.

Even what seem to be highly-skilled and professional jobs are not immune to this process. Research work in artificial intelligence [1], for example, is being directed towards computer-diagnosis in medicine. A physician, skilled in the diagnosis of some particular disease, is presented with a number of typical cases, and is asked to diagnose them and to explain the rules by which he does so. These are incorporated in a computer which then makes its own diagnoses, which are shown to the physician. By considering where he disagrees with the computer, and why, the physician can gradually refine the rules, uncovering implicit knowledge which he used unconsciously.

The indications are that this process can, with enough care and effort, lead to computer systems which compete successfully with human diagnostic skill. Then having diagnosed the disease by computer, a similar computer system could be used to select the appropriate drug for treatment. The analogy between this process, and the incorporation of the spray-painter's skill in the robot, will be obvious. It is also easy to imagine how the physician's autonomy and scope could be gradually eroded, until he came to be dominated by vast computer-banks of information, and extensive computer programs which he could not hope to understand in detail.

The machinery question

As I said earlier, it would have been easy to construct my talk around the theme of the benefits which robots can bring. It would have been equally easy to construct it around the theme of the degradation of work and the subjection of human labour to the machine, in which the robot can play its part. Either theme could be amply supported by examples from current practice, and research which is at present being carried on.

Equally, I could have adopted an even-handed approach, presenting both sides of the question much as I have already done, and then left it to you to balance one against the other. That also would have been easy, but not very helpful, and so I will go on now to the much more difficult part of my talk.

What I wish to suggest is that the ambivalence to which I have drawn attention springs from one particular view - which is indeed the predominant one - of the relation between machines and people. According to this view, the need for human skill in industry or commerce or the professions is always a relic of an unscientific past, which is always fated to be replaced by or incorporated in a machine.

Cotton spinning with the "spinning-jenny" or the "spinning-mule" was a skilled occupation until 1830, when Richard Roberts invented the "self-acting mule". Thereafter, that particular skill was no longer required. The skill of the millwright with file and scraper was made redundant by machine tools. The skill of the operator of machine tools is being made redundant by numerical control, using the microcomputer. The skill of spray-painting can be captured in a robot, some of the skill of the design-draughtsman in a computer-aided design system, and perhaps in the future skill of the physician in diagnosis can be captured in a diagnostic computer program.

This process is familiar historically, and is familiar also to those who are engaged in engineering research. It has its own vision of a better future to which it is contributing: One in which wealth will be created on our behalf by the machines; and human labour, if not abolished, will be reduced to a minor part of life. The creation of fragmented and trivialised jobs is overlooked in this view, or regarded as a temporary and transient phase. The level of skill, it is suggested, is not actually reduced by the efforts which are made to eliminate it. New skills continually arise to take the place of those that have been destroyed, though these in turn will give way to the machine.

I am myself mistrustful of arguments which suggest that our endeavours can safely be applied to undesirable ends, because they will inevitably produce the opposite result. That we can safely give all our endeavours to eliminating human skill, because the final result will be to create new and higher skills. The thought occurs to me that if we try hard enough to eliminate skill, we may succeed; particularly when we have at our command such a cheap and powerful device as the microcomputer.

An alternative view would be that human ability and skill are the most precious resource that we have, and that all our efforts should be given to fostering them and using them to the full. There is a danger also in this view, because it can become backward-looking and nostalgic. It can lead us to an exaggerated respect for earlier skills, and to the attempt to preserve them long after their usefulness has declined.

What I have in mind is something different. Machines can be used, as we largely use them, to eliminate human skill, leaving only fragmented jobs subservient to the machine. They can also be used as tools of the user, requiring a skill for their use, but rewarding that skill with an increased productivity. The skill that they call for will usually be a new one, but there is no reason why it should not be based upon an older skill and developed from it.

The difficulty with this line of argument is to show that it is indeed possible, because all our efforts for a hundred and fifty years have gone in the opposite direction. One does not have two flourishing traditions, from which to choose the better. One possibility has been lost to sight, and the problem is to show that we have a real alternative.

Yet we are not entirely without examples of the different relationships which could exist between machines and people. I have already referred to Hargreave's spinning jenny. Hargreaves was a weaver, and like all weavers in the eighteenth century, he had difficulty in getting enough materials for his work. "Arthur Young in 1770 claimed that 'they reckon twenty spinners and two or three other hands to every weaver[2]' ", while "At this time, says Mr. Guest, a weaver was under the necessity frequently of trudging three or four miles in a morning, and visiting many spinners before he could collect weft enough to keep his loom going during the rest of the day; and such was the competition he met with from other weavers engaged in the same errand, that he was often obliged to treat the females with presents in order to quicken their diligence at the wheel[3]."

The spinning jenny, then, was invented in 1764, to meet Hargreaves's own needs. Like the spinning wheel, it was worked by hand, but instead of spinning one thread, it span eight, in the early versions, and up to eighty in the later. It demanded a skill in the spinner which was related to the skill needed for the spinning wheel, but it increased his productivity many-fold. "Hargreaves contented himself, for some time after making the jenny, with spinning weft, with the assistance of his wife and children, for supplying his own loom, according to the custom of the weavers of that period, who received their warp from the wholesale manufacturers. The secret at length transpired, through an indiscretion of female vanity, and excited such tumult amongst the spinsters, and their partisans, of the neighbourhood, that they broke into his house in a riotous manner, and destroyed the hated rival of their fingers[3]."

The jenny later was widely used, though Hargreaves did not profit very much from his invention. It shows clearly enough how the spinner's skill could have evolved, becoming ever more productive, and becoming in time something new, and more advanced, though related to the earlier skill from which it took its origin. During this transformation, the machine would have remained subservient to the spinner.

In fact, this line of development was brought to an end by the invention of the self-acting mule. The machine became the master, and its needs were served by unskilled workers who moved to its demands. What is to be regretted here is not the supersession of hand spinning: I am not suggesting a return to the spinning wheel. Rather, it is the cutting short of the evolution of that skill into something new, and the reversal of the roles of master and servant between the man and the machine.

Other examples can be found today in the early stages of research into new technology, when the research workers often identify themselves imaginatively with the ultimate user. Many workers in Artificial Intelligence, for example, see their computer systems as willing servants of the user. A physician could use a computer to assist him in diagnosis; the decision, says the research worker will still be a human one, aided and simplified by the help of the machine.

I hope that this faith will be justified, but if so it will be through a departure from what we have always done in the past. The obstacles are deeply embedded in our way of thinking about the problem. We tend to compare, for example, the cost and quality of medical diagnosis done on one hand by the unaided physician, and on the other done by a computer served by operators without full medical training. What we do not bring into the comparison is a system in which the physician's skill evolves into something new through using the computer as a tool.

Still more deeply, there is I believe, an ambiguity even in the attitude of the sympathetic research worker. When the physician uses the computer as an aid in diagnosis he will usually agree with its findings, but not always. He may have knowledge, from his past experience, which has not yet found its way into the computer system, or he may suspect an unrecognised side-effect from some new drug. His evolving skill in using the computer as a tool will lie in those areas where he disagrees with it: If he were always to agree, his skill and knowledge would be truly redundant.

Yet this is a point which the research worker will probably find it difficult to accept. He will feel that the physician only disagrees because the computer produces the wrong diagnosis. A little more work will improve it, and then there will never be any need for disagreement. In short, our view of the perfect machine is one that is never wrong.

This can only be achieved in a closed system, where everything is regulated and controlled and known, and no unforeseen disturbance ever enters. Real systems are not like this, and it is a distinctively human ability and skill that responds to the unexpected, the unusual or the unknown. An alternative view of the perfect machine would be one that incorporates in itself everything that is regular and foreseeable, even those foreseeable disturbances which are the province of the control engineer. The perfect machine, however, would recognise that there will always be the unknown and unforeseeable and these are the province of the human being. It would allow the worker's skill to evolve in these areas, and would subordinate itself to him.

These comments can be applied, in their own way, to the spinning jenny and to the computer used for medical diagnosis. They also apply to my last example, which is taken from research work being done by my colleagues in the Mechanical Engineering Department at UMIST. They are developing a flexible manufacturing system, in which a numerically-controlled lathe and an NC milling machine are served by a robot. The robot takes parts for machining from racks, mounts them in the lathe or milling machine, transfers them from one to another, and finally returns them to racks after machining.

Systems like this are just beginning to come into use in industry, particularly in Japan. They are intended for producing small or medium-sized batches of parts with high efficiency. This they can do because the information needed for machining the parts and for operating the robot is held in a computer. It can be changed almost instantaneously, so that after producing say 20 of onecomponent the system can go on almost without pause to produce 50 of another.

It is usually envisaged that these systems will be "unmanned", and in Japan their development forms part of the project for the "unmanned factory." In the future it is expected that engineering design will be done with a computer: Computer-aided design. After the designer has specified the shape of the part, it is expected that he will define how it is to be machined. Then the CAD computer will produce the instructions for the FMS which will make it. Fully developed systems of this kind do not yet exist, but they will probably come into use during the next ten years.

The flexible manufacturing system, as they exist at present, are not truly unmanned, and probably never will be. They must be watched, because tools may break or coolant supply may be interrupted. Parts for machining have to be fetched and machined parts removed. New programs have to be carefully tested. If a machine is out of action in one FMS, changes in a program may be needed so that a part can be machined in another FMS. The jobs are not linked to the pace of operation of the machines, which is an advantage, but they are only remnants of what was once the skilled job of the machinist.

The UMIST system is differently conceived. The whole job of making a part, once it is designed, is to be given to the operator. He will make the first part of a batch, using the numerically-controlled machine tools and interacting with them through computer interfaces. His operations will be recorded and repeated automatically to make the remaining parts of the batch. The robot too will be programmed by the operator.

This system has technical advantages: Programming the robot will be easier, for example, because the full three-dimensional situation will be evident to the operator: If programming is done away from the FMS, there is a difficult problem of three-dimensional visualisation, and a greater demand for absolute accuracy of the robot. A separate verification of programs is not required, because making the first part automatically verifies the program that results.

Chiefly, however, the proposed system is more flexible because the operator's skill is available to deal with the multitude of difficulties and special situations which can arise. If the program is not available for a part, the machine is not held up: The operator uses it to make the first of the next batch of parts. If parts which were expected for machining have not arrived, the operator can re-schedule production. The skill which he needs to operate the system is not the same as the skill that he had before, but is based on it, and is allowed to develop freely.

Conclusion

These examples will, I hope, have persuaded you that the kind of relationship which I have proposed between machines and people is not impossible. What is needed to achieve it is chiefly a change in viewpoint, and the greatest obstacle to this is the lack of knowledge that an alternative is possible. We are not compelled to follow the path we have followed so long, of subordinating work to the machine, and fragmenting it, until the best thing we can do with the jobs that remain is to automate them out of existence. We can, if we wish, provide a path through which human skill is preserved, not by becoming fossilised in old patterns, but by evolving into new skills in relation to new machines.

I have suggested that the advance of technology, and of robots as an example, can bring to us the great benefit of machines which do not subordinate men and women to themselves; machines which accept the supremacy of human ability and skill and a... it to be more productive. I have also suggested that this will not happen of itself, and that our strongest and most persistent efforts will be needed if it is to come about. This is far from rejecting technical progress, but it is also far from an easy trust in its beneficence.

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R. Schneider

Social aspects of the use of robots: implications for working conditions and employment

1. Introduction

The rapid growth in the use of robots has sparked off a wide-ranging debate on the social implications of robot technology. The debate is characterized by two extremes: On the one hand, the emphasis is placed on the positive effects robots have by helping to improve working conditions and to protect and create jobs; on the other, their contribution to the improvement of working conditions is questioned, and it is feared they will lead to job losses.

According to robot manufacturers and users, there need be no fear of adverse consequences. Their brochures say: "Most robots replace machines, not jobs. Others relieve the employee of arduous and excessively physical work. This is the way to humanize the working environment."[2] Or: "Robots replace jobs which, by present-day standards, a human being can no longer be expected to do."[3]

What is new about these statements by employers is their admission that the working environment is in need of further humanization. They are prompted by the employer's interest in exploiting labour to the full, which often conflicts with the employee's interest in maintaining his ability to work. This conflict is clearly reflected in the high levels of stress to which employees are exposed during their work and in an early decline in their health.

A representative survey conducted in the Federal Republic has revealed that, throughout or frequently during their working lives,

- 6.4m employees (29%) are exposed to noise,
- 6.2m (28%) work in accordance with accurately defined procedures (restrictive work),

- 5.2m (24%) work in a wet, cold, hot or draughty environment,
- 4.2m (19%) work in a physically uncomfortable position,
- 4m (18%) are exposed to unfavourable environmental factors in their work (smoke, dust, gases, vapours),
- 3.8m (17%) need to use considerable physical effort, and
- 3.1m (14%) are engaged in night and shift work.[4]

In everyday working life these stress factors do not usually occur separately but in various combinations. Thus employees in 39% of jobs are exposed to two or more stress factors simultaneously, a quarter (a total of 24.3%) to three or more. Uhysical stress rises significantly in the progression from office work and the service sector to manufacturing and finally the construction industry. A breakdown into occupational groups shows that welders, solderers and machine setters in particular are exposed to very high stress, moulders, feelers, metal formers (non-cutting) and metal, warehouse and transport workers to high stress, and metal formers (cutting), smiths, assemblers of electrical equipment and other assemblers to medium-level stress.

With the aid of relevant studies, the following considers how far the use of industrial robots helps to eliminate the health hazards in paid employment that result in growing numbers of work-related illnesses and cases of early invalidity. The discussion then turns to the effects of robot technology on employment.

2. Industrial robots and working conditions

In contrast to the descriptions found in science fiction novels, robots are still far from resembling human beings. But being designed as freely programmable, movable devices, they are able to imitate simple movements of the human arm and hand. They are therefore, a suitable substitute for human labour which performs recurrent activities involved in the handling of materials and tools. Such activities, known to the industrial sociologist as repetitive work, are characterized by the following features: They leave little scope for independence in the planning and performance of the work process (limited freedom of action), their successful performance requires few human talents or manual skills (limited qualification requirements), they impose a considerable and constant burden on the employee's physical and mental capacity (high stress factor), and they restrict the opportunities for social contacts between jobs. Examples of such activities are spot-welding and spraying in the automotive industry, the loading and unloading of individual machines, assembly-line work and the packaging of products in manufacturing plants.

The conditions under which repetitive work is done do not make for a form of work that is worthy of human beings, meaning work that is practicable, tolerable and reasonable and leads to the development of the individual. The introduction of industrial robots should remedy this situation, it should help to humanize work. And yet the expectation that in at least some areas of industrial production the use of robots would bring workers and their trade unions victory in the fight they have been waging for almost 200 years to achieve an improvement in working conditions remains unfulfilled. The first factor to be overlooked was that the dominant role played by the employers in the in-company organization of work paved the way for the introduction of industrial robots: "The Taylorization of the first factories ... enabled labour to be controlled and was the prerequisite for the subsequent mechanization and automation of the production process."[5] The employers had no interest in humanizing work by rejecting Taylorization. Their primary concern when introducing robots was to eliminate jobs. The fact that highly stressful activities were automated in the process was regarded as a welcome side-effect, which they were able t exploit to ensure acceptance of robot technology in the company. Adverse changes to the work situation of employees in areas up-and downstream from robots are further evidence that the employers' declared aim of humanization work was in no way meant seriously.

This has been confirmed by sociological studies into the effects the use of robots has had. Thus a study by the Batelle Institute revealed that 53 of the 58 workers affected by the introduction of robots were moved to other jobs in the company. Most were unskilled workers. Over half were moved away from the area in which the robots were installed, while one fifth were transferred to other jobs within that area. Of the workers moved to other jobs, seven were downgraded, i.e. suffered a loss of income, while eleven were upgraded. Two thirds of those transferred were moved sideways, which in many cases resulted in a change of stress (more noise, less heat). The work situation also deteriorated as a result of a further breakdown of job content, increased commitment to work cycles and less contact with workmates.[6]

A study of the consequences of the introduction of robots at Volkswagen's Wolfsburg plant produced similar findings. Here it was found "that the elimination of a highly stressful job by industrial robots may lead to a deterioration of the work situation at work stations up- and downstream" and "that the new jobs of the production workers replaced with industrial robots in no way result in job enrichment or upgrading: the new jobs entail stress roughly as high and require qualifications roughly as low as the jobs replaced."[7] The deterioration of the work situation in the remaining and marginal jobs was principally caused by:

- an intensification of work through the addition of other activities,

- a reduction in job content at individual machines where the only jobs remaining consisted of the simple handling of materials,
- a reduction of the worker's freedom to decide where and when to take action and of work performance as a result of increased commitment to the work cycle,
- a reduction in opportunities for personal contacts, resulting in social isolation, and
- growing monotony of work performance and increased demands on attention and perception due to extended control and supervisory functions.

These findings were confirmed in a further study of the social consequences of the use of robots at the Volkswagen plant in Hanover. Here again, a survey of the employees affected by the introduction of robots revealed that the price paid for the reduction in jobs involving substantial physical stress and health hazards had been the greater exploitation of human working capacity. This conclusion is corroborated by the removal of most freedom of action from the activities of machine operators, the elimination of freedom of movement and the exclusion of personal control over work requirements. The increase in mechanization due to the use of robots also led to an increase in noise and in mental stress caused by monotony and the need for greater concentration. The use of robots to automate work processes further "resulted in a significant restriction of the range of qualifications previously required. The requirements specifically relevant to this activity, such as sensomotor skill, perceptiveness, and knowledge of the handling of tools and materials are largely reduced to the mere handling of sheet-metal parts, for which no specific skill or knowledge are needed."[8] On the other hand, maintenance personnel in particular were expected to be better qualified. But such upgrading was "not necessarily regarded by those concerned as an improvement in their work situation." Their appraisal seems "to depend on the extent to which changes in job content are felt to result in an increase in stress."[9]

In the context of changes in qualifications due to the use of robots another finding is also interesting: In the area of tool handling industrial robots are replacing activities requiring medium-level and for the most part semi-skilled qualifications. Largely because of the specific stress to which they were exposed, the workers with these qualifications had previously had a particular in-company labour market value. But "the reduction of simple to medium-level semi-skilled activities to repetitive residual jobs of the simplest kind as a result of the introduction of robots and the simultaneous decline in external stress stemming from the work process are seriously reducing the value of such workers to the company."[10] Since the required qualifications can be learnt very quickly, the employees engaged in these activities are easily replaced, and they face a greater risk of losing their jobs.

In view of the social consequences associated with the introduction of robots, they have not lived up to their manufacturer's and users' claim that they would humanize working conditions: Highly stressful jobs have not been humanized but rationalized out of existence, and some of the stress has been redistributed among up- and downstream activities.

3. The use of robots and the organization of work

The deterioration of working conditions so far noted in connection with the use of robots is not necessarily a consequence of growing mechanization. It does, however, indicate that technical and economic aspects are virtually the only factors to be considered during planning and the actual use of robots. Residual and/or marginal jobs, which themselves appear to be in urgent need of humanization, emerge as a strange offshoot of a new "humanizing technology". With robot technology likely to make further advances, the improvement of the working conditions of the categories of employees affected is becoming a problem that urgently needs solving. Past experience shows that works councils in particular can no longer take it for granted that the employers' interest in rationalization and employees' humanization objectives correspond.

In the past the involvement of works councils in the introduction of robot technology has generally been limited. Given their opportunities for a say in company decisions under the Constitution of Enterprises Act, this involvement has been largely confined to "preserving the status of those potentially concerned as part of a general effort to maintain standards already achieved."[11] Above all, this has meant preventing actual redundancies and losses of income due to downgrading. Works councils have not, however, paid sufficient attention to aspects of the work situation itself, such as working conditions, the way work is organized, qualification requirements, etc. The main reason for this has evidently been not only an inadequate in-company information system but also the tendency for works councils to view the introduction of robots optimitically as a means of improving working conditions. Studies of the social implications of the use of robots clearly reveal that works councils are far from adequately informed of company plans and decisions and that insufficient account is taken of the provisions of the Constitution of Enterprises Act.

In line with the findings of past studies, it can therefore, be said that, if employees are to press their demands for the improvement of working conditions where robot technology is introduced, employers' planning and decision-making processes must become more transparent and information on their rationalization objectives and the social consequences of such measures must be improved. Works councils should use such information primarily to formulate work-orientated demands relating to the organization of jobs and work systems (establishment of specific minimum standards for the content of jobs stress, the scale of work cycles, etc).[12] This is by no means enough to ensure increased humanization. Apart from being permitted to inspect planning documents, those directly concerned must also have a firm assurance that they will be informed. This means that above all else the flow of information between the works council, shop stewards and the employees concerned must be improved. If these conditions are satisfied, works council can bring considerable influence to bear in their activities to ensure that automation and the organization of work are considered together.

The object of associating automation and the organization of work in this way is to prevent the use of robots from having adverse consequences, which have so far consisted in a deterioration of the work situation. If mechanization is not to lead to greater performance requirements, measures must be taken under personnel policies to compensate for possible increases in productivity (greater output). This can be achieved either by enlarging the workforce in proportion with the increase in production or by imposing upper limits on output. A suitable defence against demands for greater productivity would also seem to be an agreement on the manning of mechanized production systems. Newly emerging residual activities should not be transferred to existing jobs. If the range of activities a man undertakes is not to be reduced and monotony is not to increase, opportunities for job enrichment must also be provided. Simple activities should be supplemented by additional monitoring, switching and maintenance work and the adjustment of equipment. To safeguard qualifications, additional programming, supervisory and maintenance tasks should be assigned to employees working on robot-assisted production systems. It should be remembered in this context that higher-grade activities must lead to a higher grade on the wage scale, but that a wider range of activities must not result in greater pressure of work. Any output figures prescribed for the previous job must therefore be reduced to take account of new activities.

The restriction of the employee's freedom to decide where and when to take action as a result of a high level of commitment to the work cycle can be avoided by the use of suitable buffers (component stores). Minimum cycle times should also be agreed. Commitment to the work cycle determined by technical factors should be offset by additional breaks or the use of temporary replacement workers. To prevent social isolation, workplaces must not only be arranged within sight and earshot of each other: Opportunities for social communication must also be provided by arranging for breaks to be taken at the same time. Furthermore, manual and automated areas of production should preferably be separated. Delinking these areas with the aid of buffers will create opportunities for job enrichment, job enlargement and job interchange. In particular, permanent mental stress caused by monotony can be avoided by allowing workers to change jobs within the work system, which will mean arranging for appropriate training measures.

At present, equipment is largely manned by semi-skilled workers with limited qualifications. Programming, maintenance and the elimination of faults do not form part of these work systems. At company level, this results in a polarization of qualifications. On the other hand, the inclusion of programming, maintenance, fault-elimination, retooling and setting-up activities in the work system provides opportunities for safeguarding and improving qualifications and for higher grading.

In view of the high capital cost of automated production equipment, the labour costs associated with a qualified team of workers can still be regarded as acceptable. A further compensatory factor is that a work system in which the workers have higher and more homogeneous qualifications has a not insignificant economic advantage for the company: It ensures the far greater availability of the production equipment.[13]

Practical experience shows that the use of new technologies generally results in the loss of knowledge, know-how and skills, i.e. permits employees to be downgraded. For the future development of qualifications the crucial question will therefore be who has access to the know-how, usually stored in data media/programmes, and how the handling of this know-how in the company is organized. In practice, there are two alternatives: Concentration on a small number of highly qualified specialists or fairly general distribution among the members of a work system. The first, conservative variation of the organization of work dominates in most companies. The trade union policy on work organization is geared to changing this, the object being to develop qualifications further and also to ensure their fair distribution. Criteria which guide trade union policy on work organization are: Opportunities for the development of the individual, holistic job content, varied and skilled activities, opportunities to learn, opportunities for cooperation and communication and the combination of the planning and performance of work. If work is to be organized in this way, new methods and forms of training will be required. The vocational training system must be supplemented by further and continuing training schemes, which must be accessible to all employees. What is taught in such schemes must extend beyond individual jobs and work systems. Employees must be encouraged to acquire not only work skills but also social skills and knowledge.

4. The use of robots and employment

The concern of those who fear that the growing use of microelectronics will lead to unemployment is brushed aside with a wide variety of arguments. In its 1976/77 annual report the Board of Experts for the Assessment of Overall Economic Trends, for example, wrote that, although the use of labour-saving machines in companies might reduce employment, labour would, of course, be required to produce these machines and the general effect on employment would therefore be favourable. What the Board failed to realize, however, is that employers regard the use of new machines as worthwhile only "if more labour can be saved in actual production than is needed to produce the additional machines required. Otherwise, the employer's capital costs would have to rise by the same amount as his labour costs decrease."[14] In this event, the increase in employment in the capital goods industry would be confined to the period during which the new machines were produced, and the redundancies would be delayed.

Another argument is based on the assumption that the increase in the productivity of labour achieved through rationalization results in price reductions, which lead to an increase in demand and so to the reintegration of redundant workers, thus having a favourable effect on employment. This is the view adopted by the Federal Association of German Industry (BDI): "Although microelectronics may well result in the loss of jobs, new jobs will also be created. Not only does the microelectronics sector create new products: the rationalization it makes possible in production often leads to lower product prices, frequently combined with better quality. The lower the price of the product, the better its sales prospects. Increased sales in their turn create jobs or at least prevent redundancies." The BDI, therefore, concludes that "new technology is thus unlikely to increase unemployment," since the use of microelectronics "will create more jobs in the long term than are saved through automation."[15] This argument not only calls for considerable faith in the efficiency of market forces. It also underestimates the rate of growth in production, which must clearly exceed the increase in the productivity of labour if employment is to be increased. For good reason the BDI therefore feels obliged to say that accurate forecasts cannot be made of the numbers of jobs that will be created by product innovation: Its statements are after all refuted by the trend in the information technology industry itself, where production is rising and employment dwindling. It is also claimed in the debate on the effects the use of new technologies will have on employment that their introduction will increase the competitiveness of domestic companies in world markets and thus not only make existing jobs safer but also provide opportunities for creating new jobs. This argument allows of the conclusion that failure to adjust to technological changes would cause far more serious employment problems than the accelerated introduction of new technologies. On the one hand, it must be said that this argument by no means applies equally to all sectors of an economy. On the other, it overlooks the fact that a reduction in international competitiveness is in no way an automatic consequence of failure to adjust to technical change. In a system of unrestricted exchange rates it is far more likely to depend on the extent to which increases in domestic costs result in a devaluation (conversely, a successful improvement in international competitiveness leads to increases in exports and a tendency to revalue). Consequently, it is far from safe to assume, despite the constant claims to this effect, that fewer workers are made redundant by investment in rationalization than by a loss of competitiveness. Even in Japan there is clear evidence that an increase in international competitiveness through the introduction of new technologies affords no protection against job losses, although the public is not sufficiently aware of this. A survey of 10,000 companies with more than 100 employees conducted by the Japanese Employment Ministry, for example, revealed an appreciable decline in the number of skilled workers in 60% of companies using automated production methods. The employment of women, part-time workers and older employees in particular had been affected by the introduction of robots.[16]

Prompted by the debate on employment and the use of robots, the Institute of Labour Market and Occupational Research (IAB) made an initial attempt in 1977 to estimate the number of jobs in German industry that would possibly be affected. Assuming that as a rule robots will only replace jobs in which employees are paid by results and that these jobs are repetitive, the study concluded that "at the most a total of between 400,000 and 650,000 workers might be replaced with robots."[17] In a more recent study, however, the IAB comes to the conclusion that at present industrial robots are likely to replace only about 400,000 workers.[18] To explain the lower number compared with the first study, the IAB refers to changes in the structure of employment. Nonetheless, it must be assumed that the substitution potential calculated here is too low. Two factors generally support this assumption. Firstly, the use of robots will not be confined to the areas of activities assumed by the IAB, and secondly, it has based its calculations on a limited number of sectors of industry. A calculation based on major activities involving the use of tools and/or the handling of components therefore produces a far higher number of jobs potentially at risk. The maximum number of jobs in danger is then found to be about 988,000, mostly in the capital goods industries. Although this figure will not be reached in the next few years, the work of welders, assemblers, metal-workers and unskilled workers in particular is likely to be largely replaced with robots in the long term (see Table 1). Some 20%

of these activities will probably be automated through the use of robots by the end of the 1980s. According to a trade union forecast, which must be regarded as cautious, at least 28,000 robots are likely to be in use in the Federal Republic by 1990. If we accept the redundancy figures calculated in case studies of companies, this means that from 1983 to 1990 some 170,000 employees may be replaced with robots, the majority becoming redundant in the latter half of the 1980s.

The findings of the case studies of companies clearly conflict with the optimistic view taken of the effect on employment. In a study of eight cases involving a total of ten robots, for example, the Batelle Institute calculated that the net saving to the companies concerned had been four workers per industrial robot.[19] However, even greater savings were revealed by the study on the use of robots at Volkswagen's Wolfsburg plant: for every job created through the introduction of a robot, five jobs are lost. On average four jobs were lost per robot in two-shift operations. The saving per shift and year was: 1.2 workers through the mechanization of handling activities, 0.5 workers through increased productivity and 0.3 workers through a reduction in absenteeism. On the plus side: 0.3 workers for maintenance and servicing and 0.5 workers to make a robot and the additional equipment required. This gives a ratio of expenditure to savings of about 1:5.[20] This ratio does not take account of the advantages of flexible robot technology, which enables indirect savings to be made in the building of special machines and in tooling. In addition, the considerable adaptability of robots to new products results in capital savings, since fewer special machines need to be built and less is spent on design. If these effects are included in the calculation of job savings and, to be realistic, a reduction in the cost of building robots is assumed, future job savings are likely to exceed a ratio of at least 1:8. It must also be remembered in this context that industry is endeavouring to reduce handling operations by changing the design of components and the methods used to produce them. Another factor to be considered in the debate on the effect of robot technology on employment is the further development of this technology through the addition of optical and tactile sensors, since they will extend the range of applications of robots and thus further increase savings in employment.

All in all, the use of robots confirms the scepticism felt by trade unions when appraising the future trend in employment. The contribution robots make to reducing the amount of work required by society must therefore be accompanied a redistribution of what work remains through a reduction in working hours.

Table 1

Activities which can be automated through the use of industrial robots.

Occupation	Number of employees
Plastic moulders	51,200
Fettlers	10,235
Welders	120,360
Smiths	32,485
Assemblers of electrical equipment and other assemblers	131,800
Painters (industrial)	12,000
Woodworkers	20,000
Metal-workers[1]	220,000
Unskilled workers[1]	175,000
Transport workers[1]	215,000
	988,080

[1] estimated

Source: IAD (ED), Ergänzungen zum ABC-Handbuch, Mat 1/1978

Notes

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TRAINING AND QUALIFICATION NEEDS

All participants at the meeting agreed that it was absolutely essential to maintain the stock of human skills and not to allow skills to be transferred to machines, to the detriment of the future prospects for skilled and semi-skilled employment for large numbers of the work force.

There was emphasis on the need for training of the following categories:

- design engineers
- design draughtsmen
- design technicians
- toolmakers
- maintenance/technician personnel

Mention was also made of the importance of continuing adult education particularly at university level where programmes for higher grade engineers and technicians would become an increasingly important input into the European effort to maintain a viable position in the new technology industries. One speaker from a high-technology company said that, in their view, there would be a need for fewer but more highly skilled people in manufacturing, and a need for a greater number of generalists who had a good basic background knowledge of new technology processes and who would be easily moved from one job to another with a minimum of retraining. Returning to the question of continuing adult education and adult retraining for new technologies, emphasis was made on the necessity to improve industry-university liaison in training matters related to the new technologies. It was pointed out that this has been for many years a significant feature of the development of the American electronic industry and that this was something that Europe should make intensive efforts to develop.

On the question of operator and maintenance technician training the emphasis here was very firmly on the development of multi-skilled operatives. This relates to the proposed CEDEFOP project on hybrid skills with emphasis on maintenance and technician personnel. Several speakers reported difficulties in maintenance matters particularly with regard to robots and said that a robot breakdown was very costly and quite often unnecessary. Several speakers thought that the personnel actually working with robots in a production capacity should also be trained to programme and to carry out simple maintenance of the robot and that this would constitute a form of job enrichment for the operator, and would make good economic sense for the enterprise. One senior training officer from a large automobile manufacturing company gave a list of barriers to successful training in relation to the introduction of robotics, based on his own experience of introducing over 120 robots into the assembly shop;[1)]

- a knowledge gap in the individual/group which was not identified prior to training
- a language barrier, e.g. jargon, or more importantly, ethnic technological language
- poorly designed training
- poorly presented training
- training during commissioning of equipment by engineers who are not trainers
- very little understanding of the fact that training is forward planning to a sophisticated degree
- trainee rejecting the needs for training and not being properly committed

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1) Training for new technology, by R. W. Basey, Ford Motor Co. Dagenham, U.K.

The speaker said that this list was by no means exhaustive and had been drawn from his personal experience in working with approximately fifty supplier companies throughout Europe. He said that, to date, not one of the supplier companies had approached them with a training package which was complete, capable of measuring results in behavioural/performance terms, with assessment and evaluation built in. In other words, the supplier companies in general provided the absolute minimum of training as part of their marketing package.

All speakers were concerned with the need for improved management training in relation to the introduction and management of robotics and other new technology equipment. The management of innovation was a subject area that had not been fully explored, nor were current training programmes emphasising this aspect of management.

C E D E F O P Berlin

ROBOTICS DEVELOPMENTS AND FUTURE APPLICATIONS

28 NOVEMBER 1983

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