AUTOMATION

MICHAEL HOSKIN

THE flood of literature on automation which has appeared in recent months has left no one in doubt as to the importance of the subject. Most of the discussion, unfortunately, has been of the effects of automation rather than of automation itself; the public has not been allowed to acquire any background knowledge, with the result that automation remains mysterious and menacing. I came across an example of this recently, when I was asked to take part in some Staff Association negotiations on the introduction of machines into office work 'in case they try to blind us with science'. In fact all the science needed could have been explained in five minutes, and it would then have been clear that in this case there was no need for anxiety.

Until recently it was not easy for the layman to obtain reliable information on the many topics which are grouped under the heading of automation, but this situation has been much improved by the publication of an official survey[1] which is a model of lucidity and careful writing. This survey picks out three streams of technical progress: automatic data-processing, automatic machining, and automatic process-control. I shall discuss each of these in turn, describing first examples of the equipment involved and afterwards the kind of effect which this equipment is having.

We begin with automatic data-processing, which in its most advanced form is carried out by electronic digital computers or 'brains'. These computers are perhaps the most remarkable of automatic machines. They are already widely used in scientific work, for which they were originally designed, and in due course even in factories, when automatic machining has developed sufficiently, computers will be used for the overall control of production. They are also of great theoretical interest in various branches of science, and this will be the subject of a second article. To save repetition in that article, and because of their future

1 *Automation:* a report on the technical trends and their impact on management and labour. London, H.M. Stationery Office, 1956. The parts of the present article which deal with industry are based on this report.

https://doi.org/10.1111/j.1741-2005.1956.tb00768.x Published online by Cambridge University Press

importance in all fields of automation, I shall describe the working of a computer in some detail. As we shall see, they are very different from the robots of science fiction.

The word digital in their title simply indicates that they work with actual numbers, like the abacus on which we learned to count in the nursery, and it distinguishes them from analogue computers in which a physical situation is created which is mathematically analogous to the calculation in question and the appropriate physical quantity is then measured to obtain the result. A slide rule is an analogue computer which depends mathematically on the fact that use of a logarithmic scale replaces multiplication by addition, and physically on the fact that the lengths of two pieces of wood can be added by placing them end to end. It is a convenient tool for a man who frequently has to perform a particular calculation, namely that of multiplying numbers together, but for a calculation involving addition it is useless. An abacus, on the other hand, has beads which indicate the digits of a number; it can be used for any of the elementary operations of arithmetic, and its answers involve no measurements with their attendant inaccuracies. The 'electronic brain' is simply a digital computer which has valves and other devices to give it speed. Arithmetically, such computers can do little more than add, multiply and subtract, but they perform these operations at the rate of thousands every second, a speed which no purely mechanical computer could attain.

The fact that an electronic computer is limited to working in these elementary arithemetical steps is not a serious handicap, because by approximations almost any calculation can be broken down into a succession of such steps; but it does throw a heavy burden on the 'programmer' who prepares the problem for the machine. Most of the instructions in the final programme will be as simple as 'Add the number in register 1 to the number in register 2', and because the machine slavishly carries out one by one the orders it is given the programme is of little use until it has been entirely freed from error. This means that the reduction of the problem into a programme of elementary instructions, the coding of these instructions and the preparation of the punched tape or other means by which the programme is to be fed into the machine must all be completely correct. The gradual elimination of error is a tedious process, particularly when it is not certain whether the programme or the machine is at fault. It happened recently, for example, that a day was spent in the search for a programming error when in fact the engineer had forgotten to mention he had removed several valves. Only a little experience of these machines is needed before one realizes how limited and pedestrian they are, and how misleading is the description 'electronic brain'. They have none of the almost-magical powers commonly attributed to them: before they can be used for any calculation, the programmer must have drawn up the succession of steps correct to the last detail. But they do work with almost unbelievable speed, and, considering how complex they are, with remarkable reliability.

It seems at first sight that the days and weeks spent in preparing a programme would be better employed on the actual computation. If the machine needs such detailed instructions, why not simply carry out the arithmetical steps oneself? The answer to this question varies from case to case. Occasionally, in fields such as meteorology, the arithmetical steps can be stated in advance but the results are needed too soon after the data become available for human computers to be of use. With a machine the programme can be prepared in advance and the data inserted as soon as they arrive; in this way the results are obtained much more quickly than would otherwise be possible. Usually, however, the value of a programme lies in the fact that, once written, it can be used any number of times. This is most obvious in data-processing in offices, where the same operations are performed day after day with different sets of data; once the master programme is complete the work can be handed over to routine clerks. In a similar way, parts of earlier mathematical programmes can be used again in subsequent work, and to make this easier manufacturers of electronic computers often organize libraries of programmes.

There is in addition one basic simplification which can be made in programme-writing itself. In almost every calculation a very great deal of repetition occurs, and so to write a programme with each instruction appearing separately would involve the programmer in copying out sets of instructions many times. Fortunately, this waste of time can be avoided by the use of 'conditional' orders. Suppose, for example, a set of instructions is to be repeated forty times at one stage of the programme. The programmer may begin by putting the number 40 in register 1 and continue with first the given set of instructions, then the instruction 'subtract 1 from the number in register 1', and finally the conditional order 'go back to the first instruction of the set *unless* the number in register 1 is zero'. The machine then repeats the set of instructions until after the fortieth repetition the number in register 1 is zero and the machine proceeds to the next order in the programme. Sometimes the number of repetitions is not known in advance as it was in the example, but depends instead on the results of the preceding computation. By allowing the programmer to deal with such cases conditional orders are of great assistance to him, and they are also behind much of the theoretical interest there is in computers. But although digital computers are sometimes loosely spoken of as making a choice when they obey a conditional order, such an order no more involves free will than the conditional order given to a car-engine by pressing the start button, 'Start if the ignition has been switched on'.

When the programme is complete it is fed into the machine by some such means as paper tape punched with holes or magnetic tape with patterns of magnetic spots. After the whole of the programme has been taken in and recorded the machine begins its computation, and if it is in good working order and the preliminary work has been freed from error the results will be punched out without further effort on the part of the operator. Every few minutes the machine performs millions of operations, and it is perhaps surprising that so complex a piece of electronic equipment ever produces the right answer. Of course elaborate precautions must be taken. In their extreme form these involve two differently-wired machines which do the same work and compare notes after each step; but a few simple checks built into the machine and further checks incorporated at each stage of the calculation will prevent all but the most occasional error from passing unnoticed, and regular maintenance by two or three engineers will keep the machine in good working order for perhaps three-quarters of its time.

Most existing computers were designed for scientific work and, in this country at least, the auxiliary equipment desirable if they are to be used for office work is still in the experimental stage. This equipment is needed because in scientific work the results the machine finally produces are few in comparison with the arithmetical operations needed to arrive at these results, and the existing machines with their great internal speed but slow output are very suitable for the task; but in office work only simple arithmetic is required and the speed at which the computer operates is dictated by the speed of the output. In spite of this handicap, however, computers are being used in offices in increasing numbers, and it may be interesting to see how the changeover takes place in a typical case.

A company is thinking of using a computer in its clerical work, and particularly for the calculation of its payroll. Unless the number of employees is large enough to warrant the purchase of a computer, the company may have to be content with hiring time on an existing machine, but in any case the first step is to make a careful study of the present office procedures, which will have to be re-organized into a form suitable for automatic computing. If when the study is finally complete the company decides to go ahead with the purchase of a computer there will be a further delay before the machine is installed. To this must be added the weeks subsequently spent in testing the reliability of the machine by comparing its results with those obtained by the old methods, so that in all it will take at least one year and perhaps as many as three before the computer is working effectively, and there is therefore no possibility of sensational cuts in staff taking place unexpectedly.

Once the computer is of proved reliability the staff will gradually be reduced to perhaps as little as a third of its original strength, and several of the survivors will be engaged in work that is very different in character from that to which they have been accustomed. They may also have had to move their homes, if the offices now grouped around the computer were previously dispersed. On the other hand, in an organization large enough to possess a computer there will be many other clerical posts into which the redundant staff can be absorbed, and although these changes of scene and occupation may not always be welcome, there seems little likelihood of actual unemployment of office workers for a considerable time to come. The trend towards unemployment will be partly offset, at least for the higher clerical staff, by the fact that a computer is most economic to run when it is used for long hours daily and so programmers and operators are needed to keep it occupied in the periods when it is

https://doi.org/10.1111/j.1741-2005.1956.tb00768.x Published online by Cambridge University Press

not required for payroll work. The machine will be used to produce detailed inventories and other aids to business efficiency in a more prompt and complete form than used to be possible. It is true that in some cases the purchase of a computer is said to have led to sweeping reductions in staff, but one must beware of sensationalism. When a computer is claimed to be doing the work of a hundred clerks, it does not necessarily mean that a hundred clerks ever did the work.

We now turn to the second and third streams of technical progress discussed in the official survey: automatic machining and automatic process-control. An important feature in automatic machining has been the development of transfer machines. The one given as an example in the survey is used in the production of crankcase castings for cars. At one time as many as twenty machine tools were used before the casting passed to the fitting shop; nowadays all these operations can be carried out on a single transfer machine. The casting passes automatically from one position to the next on the machine, and at each position it is clamped into place and the appropriate tools come into play. When the tools withdraw the chips are blown away by compressed air, the clamps are released, and the casting moves automatically to the next position.

As these machines increase in number and complexity they will undoubtedly give rise to serious employment problems, both during the temporary dislocation of work while they are being installed and afterwards. There are, however, at least two major disadvantages associated with them. The first is their inflexibility in use. For example, the product cannot move from one position until the next is clear, and so the same time must be spent at each position and most of the tools are not used to full capacity. Again, if in a line of transfer-machines one machine breaks down or one tool wears out, production is stopped throughout the line. The second disadvantage lies in their cost, which makes them economical only when a long production-run can be guaranteed. This affects the smaller firms rather than the large and will restrict transfer-machining more in this country than in America.

Another interesting example of automatic machining, still in the experimental stage, is the use of a digital computer to control machines for milling profiles. At present the profile is interpreted by a craftsman from an engineering drawing, but the same profile can be presented to a digital computer through the rectangular co-ordinates of a series of parallel-plane sections. A computer-controlled machine would be versatile and so particularly useful in small-quantity production.

Automatic process-control, which has been widely used for a number of years in such industries as the manufacture of chemicals, is based on the application of *negative feedback*. If, for example, in some process the temperature is to be kept as close as possible to a given constant, then the temperature is measured by instruments and transmitted to the controlling unit, which compares it with the given constant and through a correcting unit makes the appropriate alteration (possibly in some valve-setting) to bring it closer to the desired value. Because the measuring instruments determine the alteration in the valve-setting although the valve is prior to it in the system this is known as *feedback*, and as the feedback *opposes* changes in the temperature it is said to be *negative*.

Usually, of course, an industrial plant will have more than one such feedback system, and the control-equipment in a new chemical plant or petroleum refinery may represent as much as one-fifth of the total capital cost. Often there are a great many variables which ought to be taken into account, and in the future it should be possible to use digital computers to make the calculations and alter the controls accordingly. Fortunately, automatic process-control is already widely established, and as it is in any case difficult to incorporate new developments into existing plant the employment problems raised by these developments are likely to be small in comparison with those created by transfer-machining.

It is difficult to estimate just how automation will affect full employment, because so much depends on the existence of good relations between management and labour. Automation will be more concentrated in the large and expanding industries, so that in many cases it should be possible to find other posts for redundant workers. On the other hand, automation can cause serious unemployment in an industry where, for example, exports are falling. It may be, however, that the scare of unemployment has led to insufficient attention being given to the effects of automation on the many who remain employed but whose work is altered in character.

On those responsible for management, automatic machinery, with its inflexibility, complexity and high cost, will throw a heavy burden. A thorough grasp of the equipment will be necessary if costly hold-ups are to be avoided, and at a broader level the manager of the future will need an understanding of such varied subjects as the capabilities of a digital computer and the methods of the systematic study of operations known as 'operational research'. More managers will be scientists and technologists. In fact, as large numbers of men of high technical skill will be needed at all levels in industry, the rate at which automation develops may be determined by the opportunities for technical training which are available.

To many machine operators the introduction of completely automatic processes will bring welcome changes. When a process is only partially automatic the machine operator is an integral part of it and is often tied to the pace set by the machine, so that his work is fatiguing and unsatisfying. But when the process becomes fully automatic his work consists chiefly of a prearranged programme of routine checks. He has the satisfaction of being in charge of an imposing array of machinery and of seeing the part he is playing in the whole chain of operations; only occasionally is he called into action by the machine, as for example when it breaks down. Often his former difficult working conditions will have been replaced by the comfort of remote control. Automation, in fact, may well bring about the reversal of the tendency of earlier mechanization to create monotonous and arduous jobs, and to many it will mean the opportunity to find a satisfying occupation under the rigorous conditions of competitive industrial life.