PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Putting Things Together in the 1980s [and Discussion]

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Putting things together in the 1980s

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Only the most simple and essential of those engineering products which are rated among the accessories to living (and dying) in a modern society are discrete components produced from one piece of material. Most of these accessories – produced in large quantities and used by individuals in conducting various business, industrial, domestic, leisure and warlike activities – are assemblies of individual parts ranging from a few to many thousands.

Yet until recently relatively little thought and finance was expended in providing automatic methods for assembling these products when compared with the ingenuity and capital spent by successive generations of engineers in extending the capability of automatic machinery for producing discrete components.

One of the main reasons is that the important functions when fitting parts together have placed a premium on human attributes such as the dexterity of the human hand and the facilities of sight and touch. With a plentiful supply of labour, easily trainable to the necessary semi-skilled level, the compulsion to develop automatic machines for assembly has therefore been missing.

Now economic and sociological pressures are conditioning a change in emphasis. The paper attempts to outline how, by the 1980s, pressures such as these will have diverted a great deal of our manufacturing development effort from the way individual parts are made to the way in which they are put together and how, technically, it will be achieved.

Flow-line production is mainly concerned with the business of providing those everyday items that are increasingly regarded as the 'necessities of life' by most people in all the wealthy and not so wealthy parts of the world. So its future is very closely related to which of these things and how many of them people will be able to afford to buy or will be willing to buy.

And these products of our high-volume engineering factories known to marketing men as consumer durables are seldom single components wrought out of one piece of material, they are generally a collection of anything from a few to a few thousand individual parts which are put together by large squads of people, many of them women. So the future of the assembly operations in flow-line production is closely connected also with the capacity and willingness of people to work in the mass-production factory environment.

In a branch of industrial activity noted for its high capital investment, this situation is anachronistic and explains the fact that assembly and testing is still said to account for between 50 and 60 % of the total cost of manufacturing consumer durables. It also provides a situation rife with possibilities for change in the next 10 to 20 years.

Investment in machines which will augment or replace people on the assembly line has been sporadic and has had relatively little influence up to now on how products will be designed and made. The reason for this is that until recently products have been designed and their component parts made in a manner that placed a great deal of reliance on the dexterity and the critical faculties that the average person can bring to a job of fitting parts together. These attributes are difficult and expensive to build into a machine.

Also, the world's makers of cars and their accessories, electrical appliances of all kinds, telephones, radios and televisions, power tools, record players, cameras, tape recorders, clocks, watches, and so on have in the past been able to employ enough people to meet market demands for their products. These people have been easily trained to the necessary semi-skilled levels and they have been willing to earn a living on the high-volume assembly line.

So the compulsion to reduce industry's reliance on assembly operators just has not been present. Whether that compulsion will emerge between now and the year 1990 depends on a number of factors which are clearly recognizable:

It depends on world markets for durable goods which by that time may plunge or become partially saturated.

It depends either on the ability to evolve a more acceptable environment in the assembly shops which will rekindle the waning will to work in many European and American mass production factories, or on the ability to tap reservoirs of fresh, willing labour by moving production to developing nations.

It depends on the growing taste of the public for variety which some predict will sound the death knell of high-volume production.

One could speculate all day about the many ramifications of factors such as these, but from the evidence I have seen the predictions I have read and the opinions I have listened to over the past few years, I have formed the opinion that from them there emerges one probable path of progress which, stripped of the many side issues, can provide a framework for speculation.

Spending will double

Figure 1 shows that the growth in world production since the Second World War has been faster and more sustained than in any earlier period of similar duration in recorded economic history. Note the striking correlation between growth of production and growth of exports and imports. And these growth rates seem unlikely to tail off. The experience since post-war reconstruction suggests that rates of growth of output and of output per person possess considerable stability.

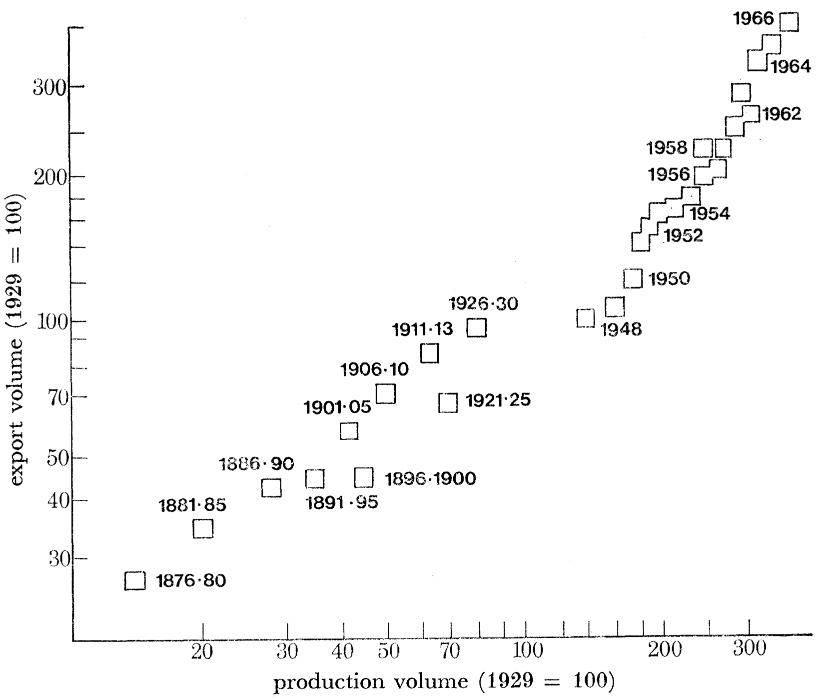

FIGURE 1. Since the Second World War growth in world production and world trade has been faster and more sustained than in any earlier period in recorded economic history.

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This is the opinion of the Organization for Economic Cooperation and Development (O.E.C.D.) who showed in a comprehensive study of the growth of output up to 1980 (O.E.C.D. 1970) that the growth of domestic product of its 23 member countries – which include all the developed nations outside the Communist bloc and a cross-section of the developing nations – doubled in the decade and a half up to 1970. Estimates from individual countries – which gave an overall growth of between 65 and 75 % between 1970 and 1980 – have led to a 'strong presumption' that the gross domestic product will again double in the next decade and a half up to 1985. Between now and the end of the century it is likely to quadruple.

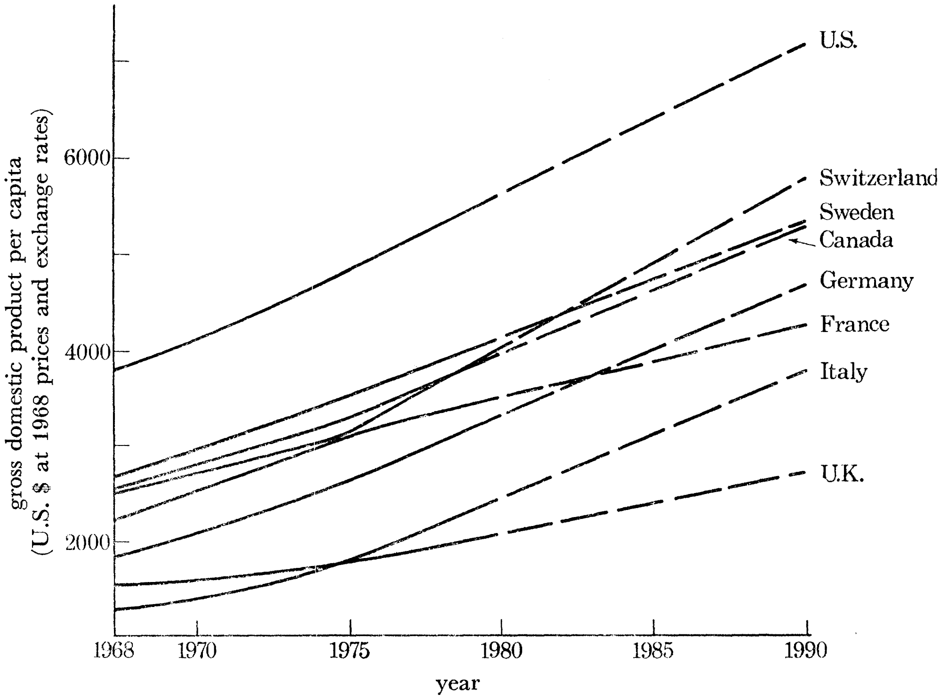

FIGURE 2. During the 1980s richer European nations will easily reach present output per head of U.S. Smaller European countries should be approaching present output per head of more industrialized European nations (source O.E.C.D.).

Projected growth up to 1980 for the richer European nations, figure 2, when extrapolated, indicates that during the 1980s these countries will easily reach the present output per head of the U.S. The four smaller European countries, Spain, Turkey, Greece and Portugal, should be approaching present levels of output per head of the more industrialized European countries. America will continue to forge ahead to a point were by 1980 its gross national product per head has increased a further 40 %. These predictions, made in 1970, were reaffirmed in 1972 (O.E.C.D. 1972) despite the intervening recession.

There is quite a range of growth rates between different countries, and the O.E.C.D. area is not going to grow as one big happy family. Some will grow fat on the markets of others. Competition will be intense, particularly as the value of exports and imports is predicted to grow up to the 1980s on average 25 % faster than the rate of production. One would suspect that trade in consumer durables will exceed this average.

But how will this increased wealth be spent? Again the O.E.C.D. member countries have made predictions (O.E.C.D. 1970). They expect that private expenditure will grow at about

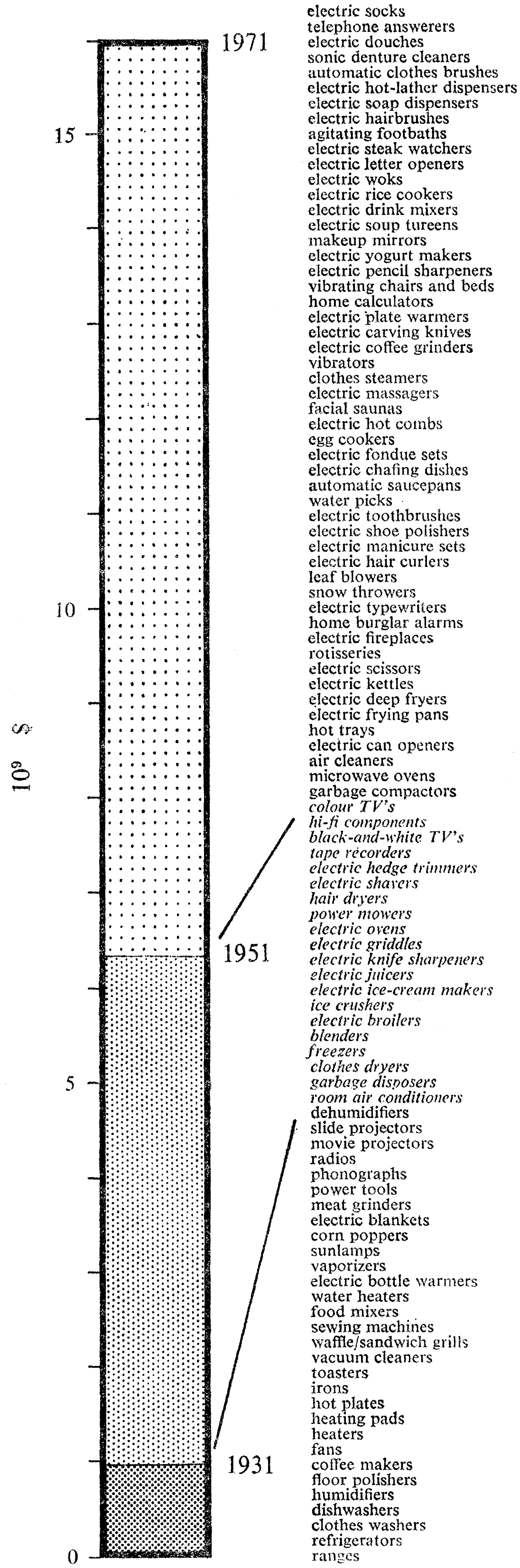

FIGURE 3. Sales of electric appliances in America began to build up in 1930s. Value and variety expanded at an increasing rate until in 1971 value of sales was $\$16 \times 10^9$ ($£7.3 \times 10^9$) (source *Fortune Magazine*).

the same rate as the value of production, and that the proportion of this private expenditure spent on durables such as household goods and transportation will increase from around 15 to 17 %.

In the 1980s we therefore have the prospect of a decade during which spending on consumer durables will reach a value that is double today's demand and during which international trade will more than double itself.

Take for example motor cars. If the people in the richer European countries have the same levels of vehicle ownership in the late 1980s as the United States had in the late 1960s, we could expect the total number of road vehicles in Europe to double from around 65 million now to some 130 million by 1990.

As a pattern for future expenditure it is also interesting to see the explosive growth up to now in the volume, variety and value of electrical appliances bought by Americans. The average American home includes a small truckload of household appliances. Figure 3 shows the great growth of retail sales which began to build up in the 1930s with the development of what the American publishers of this illustration described as 'such basic home appliances' as refrigerators, coffee makers, clothes-washing machines, dishwashing machines, floor polishers and other items which you can see are shown at the bottom. The variety of goods available expanded steadily during 1931–51 (shown in italics) and was even more explosive during 1951–71 (shown at the top) to reach the staggering total of $\$16 \times 10^9$ or at today's (November 1971) exchange rates about $£7.3 \times 10^9$.

Fewer people

To meet this next doubling of consumer demand up to the mid-1980s, however, the pressure is now on to get more out of an assembly line worker who will become increasingly scarce, more and more expensive and, in certain industries, more militant. The proportion of the labour force which is producing goods in industry is predicted by the O.E.C.D. to decline in all of the more advanced manufacturing nations (for example from 31.0 to 28.7 % in the States and from 43.7 to 38.3 % in Sweden (O.E.C.D. 1970). With the increase in working population this means the number of people employed in producing goods will probably rise by a mere 6 %. The rest will join the ever-growing flow of workers into service industries. In America and Sweden by 1980 it is predicted that services will account for up to two-thirds of all jobs.

In the 15 years up to 1970 mass producers have certainly equipped and organized their machine shops to meet the doubling of demand for their products. But on their assembly lines cheap immigrant labour flooding to the more advanced European countries has mainly been used to boost output.

In France, Germany, Luxemburg, Switzerland and Sweden total population grew at a rate at least 50 % higher than did the native population. At Volkswagen, for example, the factory signs are in three languages and German is not the first. Renault has predicted it may not employ a single French worker by the end of the decade, while more than a third of the manual workers at Volvo and Saab are Finns, Danes, Yugoslavs, Italians, Turks and other foreigners (*Economist* 16 September 1972). With few exceptions this sharp contrast in investment between component production and assembly applies in the manufacture of consumer durables all over the world. When *Metalworking Production* (1972) carried out its survey of machine tools and production equipment in Great Britain last year it found that there were just over 2000 assembly machines installed in the whole of the engineering sector, including even the simplest devices which could boast product transfer between work stations. In the United States, where capital employed in assembly is probably more intensive than anywhere else in the world, there were, according to *American Machinist's* 1968 survey, 13407 assembly machines – still a paltry total. Exchange of information with official bodies in other countries leads me to think that only West Germany has a bigger investment in assembly machines than the U.K.

But labour is not only going to be scarce, it is going to be much more expensive. Figure 4 shows what has been happening to wages in engineering in a number of the leading industrial nations during the 1960s and there is little reason to think that this pace of increase will ease. Also shown are the wage rates for women in certain countries. Considering that most assembly-line workers outside the heavy final assembly lines of the car and heavy domestic appliance producers are women, think what will happen when equal pay comes to Britain, for example, in 1975.

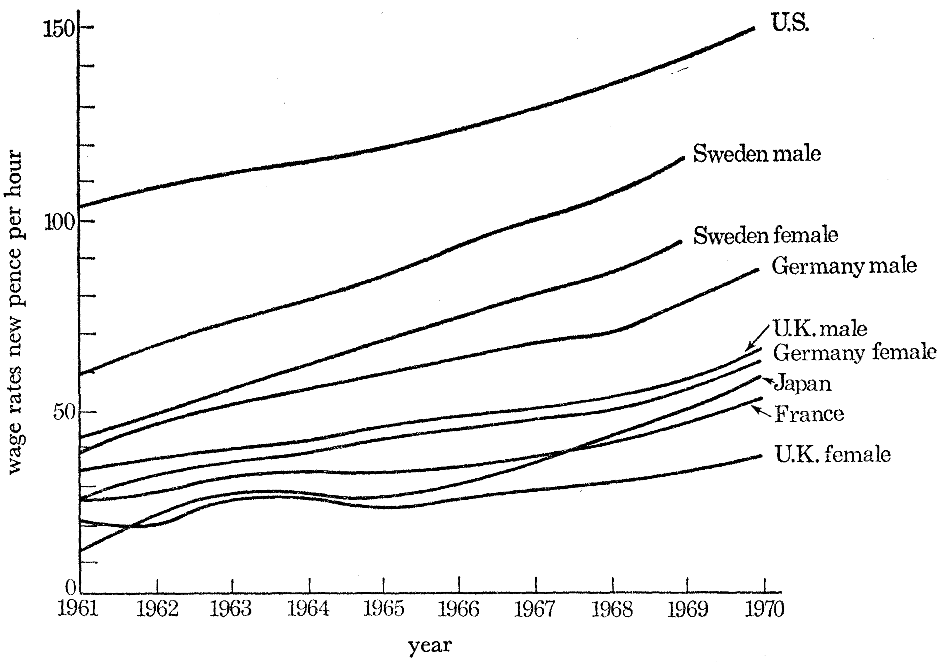

Figure 4. Wages of engineering workers in all leading industrial nations are steadily increasing. The curves for women indicate the potential cost increases of goods when women are given equal pay (source United Nations).

On a longer term basis figure 5 shows the trend in engineering wages in Britain over the past 33 years. It has risen from just over 5 new pence per hour to around 66 new pence per hour.

But the one situation in flow-line assembly which will probably act as the greatest stimulant to progress will be people's increasing dissatisfaction with the job – despite wage rises – which leads to industrial strife, heavy labour turnover, absenteeism and an acceleration of the reduction in the number of people available. Nowhere is the trouble greater than in the final assembly lines of the car makers where conditions are probably at their most demanding. The layout of the line can breed isolation of the worker, the work is noisy, can be heavy and is monotonous without providing that satisfying rhythm that you get with lighter, well-studied assembly work, and the problem is growing as the young people who make up the potential labour pool become better educated and more selective about the work they want to do.

In Sweden they give up the job. Volvo had a labour turnover of 52 % in 1969 and last year it was running at 30 % (Willatt 1972). In America they stay away and it is largely absenteeism that has limited Detroit's ability to build cars faster. Productivity per man hour in the U.S. automobile industry increased on average only 3.6 % annually from 1957 to 1970. Everywhere, including the rest of Europe and Britain, they strike.

Sweden's two biggest car makers, Volvo and Saab, are however installing facilities to make the job more interesting by, in effect, disassembling their assembly lines. Both these companies in certain areas are successfully using group production methods in which car and truck components are assembled by semi-autonomous groups. At times they can decide in what order they tackle their tasks and even who their foreman will be. They are also rotating some assembly-line workers to different jobs.

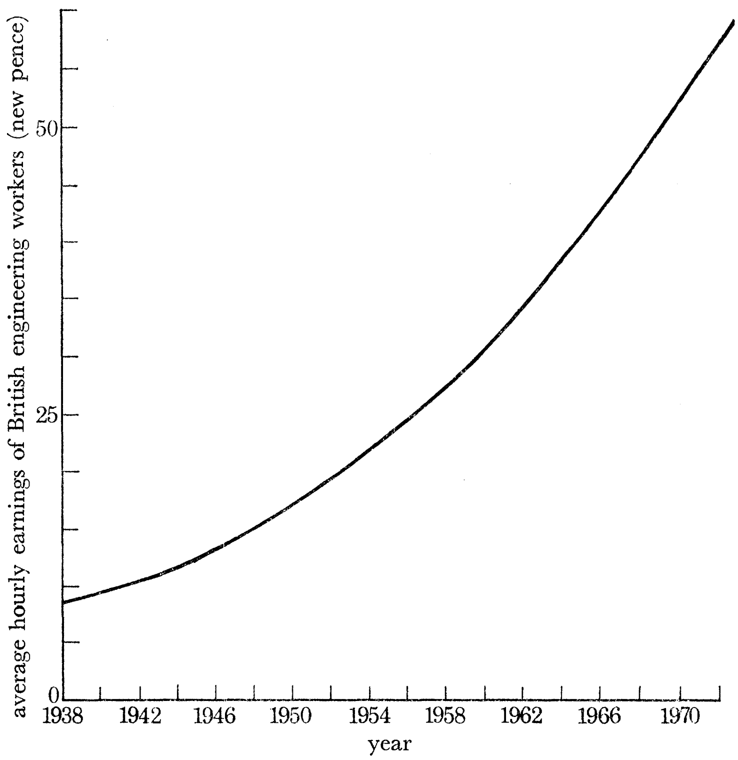

FIGURE 5. Hourly rate for British engineering workers has risen from the equivalent of just over 5 new pence in 1938 to around 66 new pence in 1971 (source Department of Employment and Productivity).

But, remembering that European car demand in the 1980s could equal present American demand, it is interesting that executives at General Motors, Ford, Chrysler and American Motors all insist that team assembly is simply not fast enough to produce the 10000000 plus cars and trucks that these 'big four' car makers turned out last year (Volvo and Saab together assembled just over 300000 vehicles in 1971).

Despite their failure so far to come up with a satisfactory alternative, the American car makers in refusing to emulate the Volvo experiments are probably expressing the fears for the long term of many mass producers, who intuitively sense that their products cannot be assembled by group methods in the quantities that are required today, let alone those that will be demanded by the markets of the 1980s.

My feeling is that intelligent job enrichment, based on concern for the wellbeing of the employee, is a valuable interim measure. But on the mass assembly line – faced with satisfying enlarged, more competitive markets with a better educated, less tolerant work force – it will

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prove to be economically necessary and sociologically more beneficial to concentrate on developing the means of reducing, where possible, the almost total reliance on large numbers of people. But how will this be done?

The glib and easy answer that is often given is to say 'where possible replace people or augment their efforts by machines or by what are now becoming known as "industrial robots", starting first with the more unpopular and degrading tasks'. But it is proving to be painfully expensive to impose a machine on the assembly process, without restructuring certain basic philosophies about the design, the manufacture and the marketing of consumer durables. A few British companies have successfully negotiated this phase – some of whom I see represented here today. It is their experience and predictions and the views of their counterparts abroad that I am going to draw together, to present what is the likely pattern of successful progress towards the less labour-intensive assembly shops of the 1980s.

Design for assembly

The materials, the forming techniques, the quality control procedures and the computer-control techniques for creating a satisfactory environment for the reduction of assembly effort by the proper attention to the production of component parts exist now; and they are constantly being enriched. It is largely a matter of exploiting this growing wealth of materials and processes and so organizing the machine-shop environment to produce an acceptable component economically and with simple assembly in mind – because the *real impact on that* 50 to 60 % *of total manufacturing effort* which is absorbed by the assembly function is going to be made by conducting product design and manufacturing considerations with the predominant aim of making the assembly process easy and reliable, either for people or for the machine.

These two aims are not so different. The product that has been designed for easy assembly by machine is also very easily assembled by hand. So much so, that a number of major product design or redesign schemes I know of, so reduced the manual assembly effort that no financial justification remained to implement the original intention of automatic assembly.

To make this concept evolve, design and production departments will continue to become more closely merged to develop what would be normally groups of components for moulding as a single part, with components such as shafts and bearings inserted into the die, and in materials such as stainless steel. More precise forming techniques will become widely adopted. Among these techniques will be precision diecasting, precision plastic moulding, powder metallurgy, investment casting (now developed as a continuous process), fine blanking, high-energy-rate forming and a number of hybrid techniques such as forged powder parts and plastic and metal composites. These methods will produce, in a single forming operation, contours too intricate to cut on a single machine tool. Moreover, features that make for easier orientation, handling, location and fastening to simplify assembly will be designed into the component without complicating its manufacture.

Products which are now frequently assembled from individual parts will be broken down into self-contained subassemblies that can be independently assembled on a series of relatively simple, lower cost, assembly devices. Yet within these subassemblies more attention will be given to designing assembly so that a major component acts as a jig and other parts are added in simple sequence. As far as possible separate fasteners such as screws and rivets will be eliminated and a greater use made of fusion techniques, adhesives, soldering, clip fastening and twisted tab joining techniques.

The implementation of this philosophy of design for assembly will make it necessary for consumer durable design and marketing to move away from present concepts of dismantling and repair and embrace the philosophy of the mass producers of consumer disposables such as light bulbs and batteries, who also, I suspect, ask themselves how long the product should last and what is a reasonable price for that length of service.

If anyone has ever invented repairable light bulbs or an everlasting battery the idea has been bought up and quickly buried! If it had not been, our lamp-making plants and our battery-producing factories would be reduced to massive repair shops, having satisfied most of the world demand a long time ago. They have instead created a perennial market which in turn has given them production volumes that over 30 years ago justified a capital-intensive approach to assembly, which has been keeping prices down ever since.

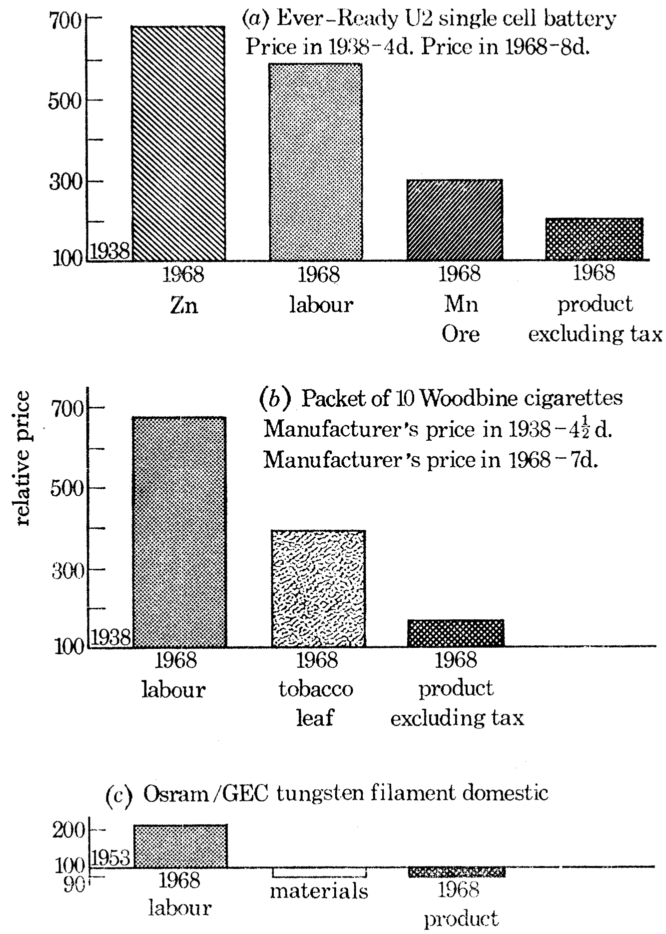

FIGURE 6. Average product prices of certain consumer disposables have at the most doubled since the 1930s. Design for production and automation (largely in assembly functions) has counteracted five to sixfold increases in materials and labour costs.

It was around the mid-to-late 1930s that these industries started to change from being labour intensive to capital intensive and a great deal of the capital went into equipment for what are parts-manipulating and fitting operations, which account for about 70 to 80 % of the manufacturing effort.

Figure 6 shows that, from about that time up to the late 1960s, the average product prices of British companies producing some of these consumer disposables have, at the most, doubled, while on average labour costs and material prices have risen five- and sixfold. I do not have the figures for the last 4 years but I would be surprised if these products had been as susceptible to inflationary trends as the products of more labour intensive industries.

And wherever they decide to manufacture, these 'consumer disposable' producers have now developed products that could hardly be produced at all, let along be produced economically, by reverting to even the cheapest manual labour. They are not interested in exploiting hoards of little girls to frantically assemble lamp bulbs and batteries in Singapore, Thaiwan, South Korea and other cheap labour areas. They know too well the threat of cost escalation through the rising standards of living that are the inevitable accompaniment to economic growth. They tend therefore to adopt the same capital-intensive manufacturing approach in their various plants throughout the world. In common with a few other people, I view the switching around of labour-intensive, large-volume manufacturing facilities, purely to grab a temporary labour cost advantage, is capitalism gone mad. Mass production operations should be so equipped as to be placed as a capital intensive industry in any part of the world to take advantage of market developments.

Now, no one thinks twice about throwing a lamp bulb away or a battery or even, these days, a hypodermic syringe. These and many other discards we accept. Why then do we rebel at throwing away, say, an alarm clock or radio when they first fail? Is there a psychological barrier, conditioned by the days when these accessories were so expensive in relation to spending power that they had to be amortized over a life-time of service? It certainly is not an economic barrier. An alarm clock can cost a mere £1.64. Should I grumble if after two years of reliable service it fails and I have to replace it? Often products such as these cannot be mended because they cannot be taken apart but then that is not likely to matter because, contrary to popular belief, products that are created to be machine assembled are more consistently reliable than their manually constructed equivalent. The rigid quality regime imposed on components and their mating capabilities by the inability of the assembly machine to accept subquality sees to that. In the unlikely event of a clock such as this failing under guarantee, the price to the manufacturer of replacing it is probably something under £1; less than the cost of an hour of a skilled repair man's time.

A transistor radio can be bought for around £4.50 and has a factory price of much less than that. The marketing arguments in favour of a throw-away concept here are exactly the same as for the clock.

These and many more of the items whose permanence today we take for granted will be tomorrow's new sealed, unrepairable consumer disposables. They will have a longer life but they will be designed and marketed on a basis that, during the next 20 years, will condition methods of manufacture and levels of investment in the assembly process consistent with mass-replacement world markets and made at price levels that make the replacement concept acceptable to the customer.

We might even find a new term for them like 'long-term disposables' or 'semi durables'.

In terms of production volume it means that the market saturation so feared for many of today's consumer durables is only transitory. I think, however, it is vital to reaffirm that this evolution will *not* lead to a lowering of standards of quality. Quality of performance, without recourse to repair, must be and will be higher, and will speed the application of more stringent measuring, sorting and selective techniques for the components of assembly.

For over twenty years now, domestic refrigerators and freezers have been based on quite complicated and expensive sealed compressor units which cannot be repaired, and which must be discarded if they fail in use. The secret is that, by clever design, the life expectancy is high and frequently exceeds the useful life of the appliance itself, which is set by obsolescence.

Basically it all comes back to totally rethinking product design for predetermined, consistent levels of performance and life, consistent with a manufacturing routine that satisfies the various levels of quality on the basis of 'what is assembled need not be, indeed must not be, capable of being disassembled'.

The nature of some consumer products will be such, however, that purchase prices still dictate longer term usage, these will include quality cars, the larger more complex household goods and those deliberately expensive 'durables' for those of us who value permanency of possession. These goods will be made up of a collection of self-contained replaceable throw-away modules. Already the car accessory and domestic appliance manufacturers are providing us with the beginnings of this trend. There are fewer and fewer accessories for even major components that are economic to repair or can even be opened up for repair.

Also, with sealed permanent-magnet motors, rugged printed circuit motors up to 1 horsepower, basket-wound motors with virtually no brush wear and transistorized brushless d.c. motors, it is doubtful whether the electric goods manufacturer will in 10 to 20 years time – maybe less – repair what is the heart of almost every one of his products. He will simply perform a transplant (but the substitute will be brand new).

Added to this will be the way in which this concept of throw-away disposable modules counters the possibility of mass assembly being compromised by what is now becoming known as the 'option explosion'. It is again particularly noticeable in the purchase of automobiles, but will certainly by the 1980s follow into many other consumer durables, as it already is doing now in the States.

This growing public taste for product variety has, in certain quarters, been regarded as the death knell of mass manufacture. But in fact automobile manufacturers are starting, quietly but decisively to destroy its effect by providing optional assembled modules, whose presentation to the final fitting line is computer controlled to provide the customer with the illusion of a huge choice.

I believe that the rest of the world's producers of consumer durables will, in the 1980s, be adjusting to the same approach.

I am therefore suggesting:

(1) That consumer spending power in the developed countries will have doubled by the mid-1980's.

(2) That markets for consumer durables will not become saturated, because the products or their component subassemblies will become consumer semi-durables with a mass replacement market.

(3) That the option explosion will be shown to be a myth that can be destroyed by intelligent, computer-controlled permutation on the final assembly line of a range of standard subassemblies.

(4) That labour to carry out the assembly function will become increasingly scarce, expensive and unwilling.

(5) That producers will not reverse production and trade trends by supplying the developed world from cheap labour areas of the globe.

(6) That we will by the very nature of the design process for the throw-away age, either simply design out the need for large squads of people on assembly lines, or augment their efforts on a large scale with machines.

How machines will develop

But how will assembly machines develop? Two recent Delphi long-range technological forecasts give clues to the way a number of people predict the role that will be played by the assembly machine in the 1980s. Dr Merchant outlined some of the findings of such a Delphi exercise conducted by the C.I.R.P. (1972). One forecast that came out was: 'By 1985 automatic assembly will be extended to the greater art of mass production operations by development of measuring, sorting and self-selecting techniques.'

Judging by the progress of the past few years this prediction will be fulfilled only if the emphasis is shifted from the way parts are made to the way in which they go together and products are designed with the predominent aim of making assembly simple and reliable and capable of being performed by a relatively simple mechanism. In fact I am not sure that it will happen so soon. There are great inroads to be made into assembly labour by good design.

Apart from a few adventurous schemes the major influence of automatic assembly will be through simple mechanically controlled machines, or by grouping some of the growing range of programmable devices. Industrial robots, for example, produce 95% of the 7900 welds on the body of the General Motors Vega car, produced in the United States. In Europe, Fiat and Mercedes-Benz use these kinds of devices to a more limited extent for welding and assembly operations.

It has been predicted that by the end of the century some 50000 of these devices will be in use (Rooks), and their impact on the piecemeal progress of automating the assembly line is anticipated to be not inconsiderable. There are now 130 car models manufactured in Japan, Europe and the U.S.A., so if the market forecasting of the manufacturers of these devices is not right, there are going to be some headaches.

Taking adaptability one step further, a computer-controlled placement device developed by the Production Engineering Department at Nottingham University has an artificial capability for 'seeing' its way to the required object, identifying it, picking it up and moving it to a new position and orientating if necessary in the meanwhile. There seems little doubt that such versatile devices will play a very useful role in smaller batch production.

As the present alien environment in many of today's mass production factories improves, all these various approaches towards assembly devices will virtually take over many of the assembly tasks now being done by people. But the placement, fastening and gauging operations will be computer-monitored and the machines themselves will be computer-controlled. This is the prediction of the second Delphi long range forecast, which I mentioned earlier, and which was conducted by the Birniehill Institute of the National Engineering Laboratory (Bruce 1971).

During the 1980s a piece-meal approach to assembly should however give way, in many industries, to a systems approach, which will combine these various types of assembly machines under computer control. Figure 7 shows a schematic representation of how the system will look using present-day concepts of individual machines.

These machine concepts may change. But however the machine units evolve from today's designs, the assembly systems concept is most likely to grow around the modular product concept, in which satellite units feed modular subassemblies into a final assembly line. A present-day application which points the way is shown in figure 8. This computer-monitored system assembles 35 different components to produce eight different models of a valve for a brake system. Optional subassemblies are fed from what are called 'supply modules' into a final assembly 'demand module'.

As I mentioned earlier, by far the most intensive usage up to now of assembly machines has taken place in America, and this has controlled to a large extent the progress in commercially available assembly equipment.

A steady-state prediction would point to a continuation of this situation. American suppliers have the widest knowledge of tooling assembly machines for individual applications which is

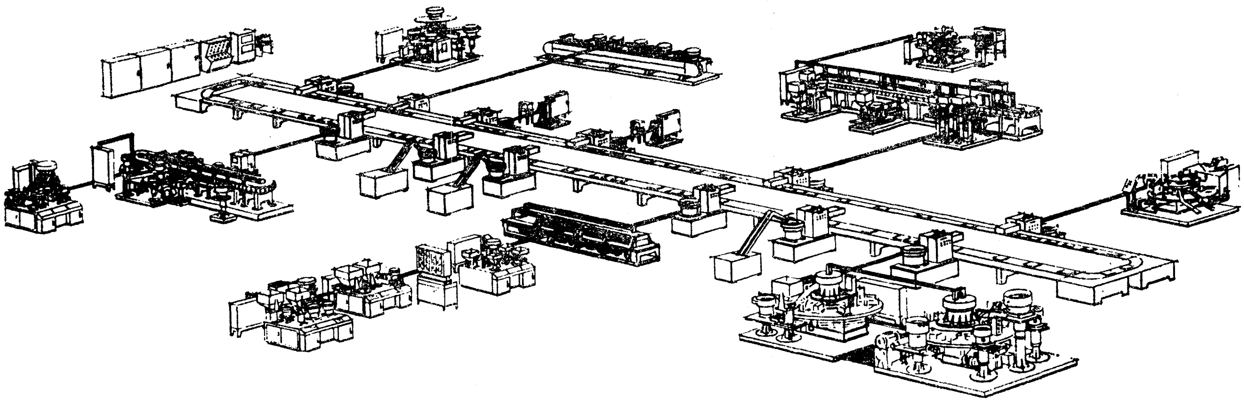

FIGURE 7. Swanson Erie 'demand system' today heralds the assembly system in which satellite units feed modular subassemblies into final assembly line.

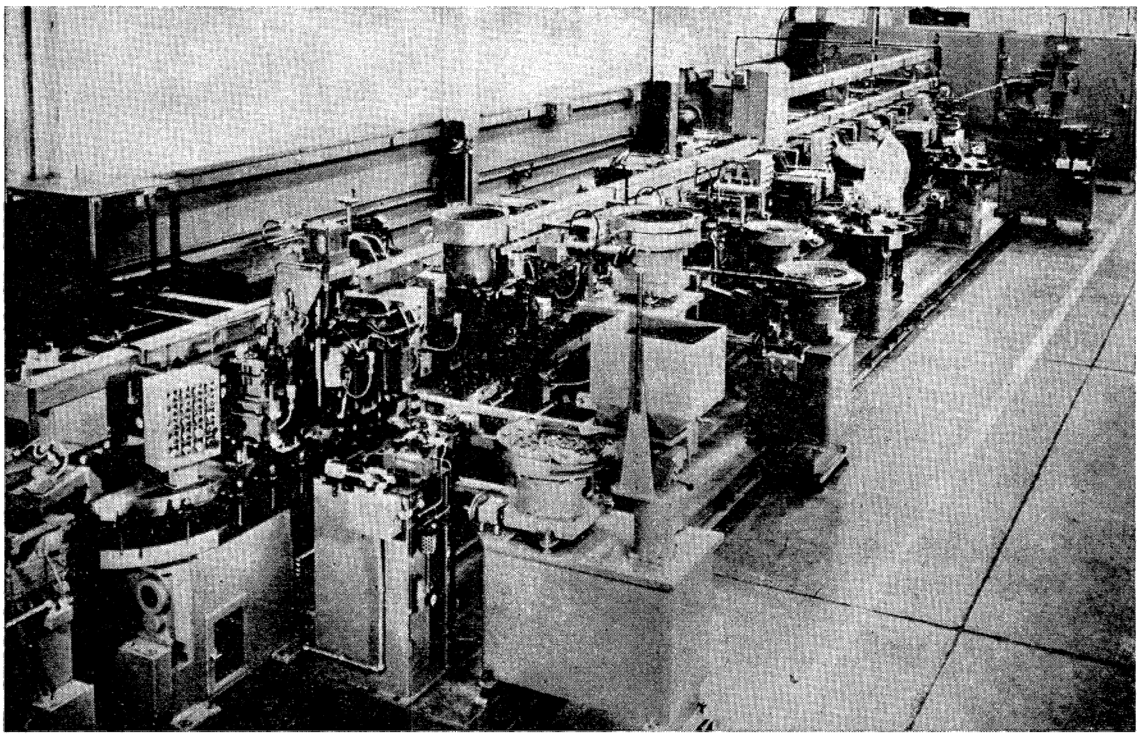

FIGURE 8. Supply modules in this Swanson Erie computer monitored assembly system feeds optional subassemblies into a 'demand module' to produce eight different models of a valve for automotive braking systems.

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all-essential, and because of their influence the domestic engineering environment is probably more easily conditioned to accept the manufacturing disciplines needed for automatic assembly.

But I think it is dangerous to assume that during the next 8 to 18 years we will not be in for a few surprises and one of them might spring out of the situation illustrated in figure 9. In this illustration the projected growth of production per head of Japan is compared with the other O.E.C.D. nations. Despite the growing resistance in world markets, O.E.C.D. seems to feel that both output and output per person employed in Japan may well increase at least twice as rapidly as in Western Europe. If this were to happen, income per head in Japan would reach the levels of the E.E.C. countries during the 1980s and by 1990 they will be hard on the heels of America. They could well be on the way to becoming the richest nation on Earth.

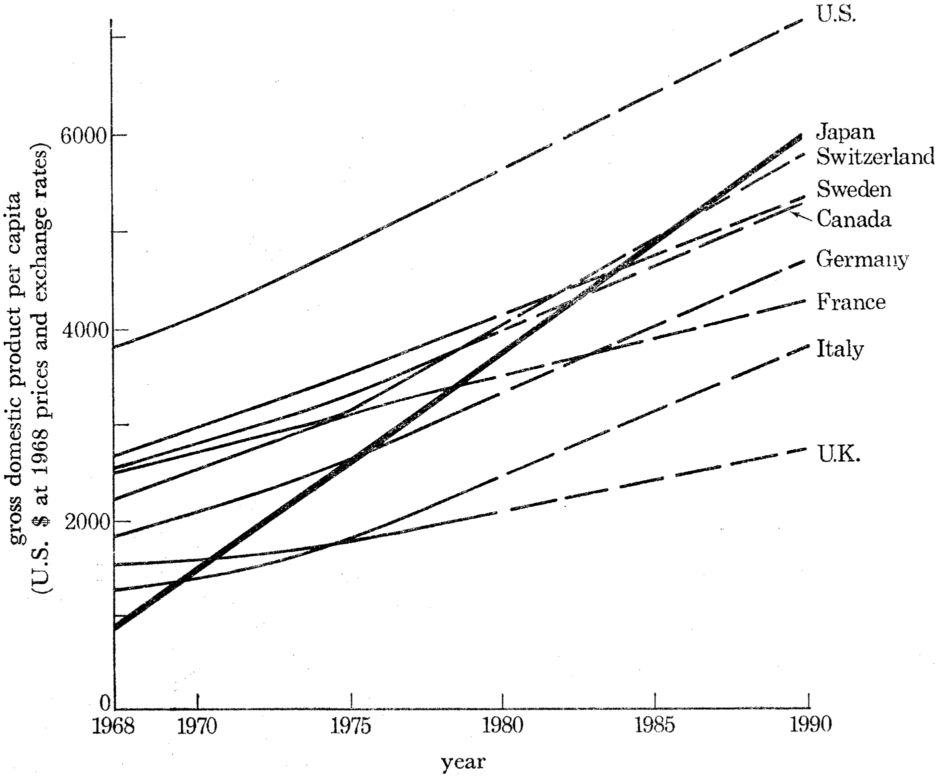

FIGURE 9. Output and output per person employed in Japan may well increase at least twice as rapidly as in Western Europe.

Now if the Japanese economy keeps on growing at around 10 % per year its most thrusting industries (many of which are engineering large batch and mass producers) are likely to keep on growing at twice or three times that rate and if an industry grows by about 25 to 30 % per year more then half its machinery at any given time is going to be less than 3 to 4 years old: thus making the industry quite competitive (Macrae 1972).

For example we found out at *Metalworking Production*, when we were conducting our survey of machine tools, that Japan had installed 765000 metal cutting machines alone between 1967 and 1971. To put this in perspective in Britain we installed 290000 metal cutting and metal forming machines between 1966 and 1971.

In addition, with growth rates such as these, industry gets into the habit of being expansive and there are many people who work full time searching for new materials, designing products,

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equipping new production facilities and investigating new markets. Manpower pressures are even now starting the Japanese on the road towards building up an expertise in assembly devices. It may be, therefore, that in the business of reducing the need for people on assembly lines, the centre of knowledge will shift from West to East.

I would like to express my appreciation for the very practical help given by the staff of Hazleton Memorial Library of the Institution of Production Engineers and for the advice given by Mr R. Webb the Institution's assistant secretary (technical) and to all those people, in many parts of the world – too numerous to mention – who helped piece together the picture of how flowline assembly is likely to develop over the next 10 to 20 years.

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Discussion

Mr Woodhead (*I.C.I. Fibres Ltd, Harrogate*) said that he was struck by the parallels in the synthetic fibres industry to the components and other metallurgical industries which had been dealt with earlier.

Like the processing of ore into steel, the synthetic fibres industry starts with a large-scale petrochemicals-like operation and rapidly proliferates into a mass of increasingly labour-intensive operations. The challenge of the 1980s is to rationalize these operations and to make them *more* labour-intensive while maintaining the variety. Then there are various operations, such as making a filament bulky and colouring it, which are carried out by different trades. All these operations are receiving close attention at the research stage, and it is hoped soon to produce cloth, and perhaps even the garments themselves, based on far simpler patterns than are used at present, directly out of a monomer.

Professor N. Kurti, F.R.S. (*Clarendon Laboratory, University of Oxford*) congratulated Mr Iredale on the wonderful dexterity with which he had managed to land all his disposables in the garbage cans. He noted that the great problem of the future might not be a shortage of raw materials, but how to dispose of the disposables. He questioned Mr Iredale's acceptance of an exponential growth rate and remarked that it might no longer apply to the car industry. He said that he hoped to refer to this aspect in the general discussion.

Sir Alastair Pilkington, F.R.S. (*Pilkington Brothers Ltd, St Helens, Lancashire*) said that he had observed two conflicting trends: on the one hand, the need to produce more because people want more no matter how much they have got already; on the other hand, the reaction of society against behaviour which seems to be irrational. If companies are to give an assurance of employment to their workers and remain competitive, they need growth.

Mr Iredale believed that despite pressure from conservationists and environmentalists on the need to be able to recycle all the materials that we use, for the next 20 years the pressure of consumers for more material goods would be stronger. After that, however, the situation might reverse itself, and he warned that our recycling processes needed to be more efficient and better organized.

Lord Avebury (24 *Rivermill, Grosvenor Road, London, S.W.* 1) asked whether Mr Iredale had considered his comparative figures for gross domestic product in terms of the consumption of raw materials and whether this rate of consumption would be realistic in the 1980s. Mr Derek Ezra of the Coal Board had already predicted increased interest in the use of coal for energy instead of liquid hydrocarbon fuels. He suggested that if Americans were given higher disposable incomes they would not buy more motor cars, but string orchestras or something similar which did not make the same kind of demand on raw materials.

Mr Iredale said that he had not been able to obtain any satisfactory figures on the consumption of raw materials. There was little prospect of running out of fuels which were needed to make the newer materials such as plastics.

Professor M. W. Thring (*Queen Mary College, London, E.* 1) thought there were four reasons why growth could not continue indefinitely. The gap between the rich and poor countries of the world cannot be allowed to increase any further. We will be facing a grave shortage of raw materials in the fairly near future. There is a limit to the disposal of disposables, and finally, if the average life of a consumer durable is two years, then the lifetime has a Poisson distribution and many will fail after one month.

Mr D. Firth (*National Engineering Laboratory, East Kilbride, Glasgow*) said that freedom of design could be inhibited by the development of automated processes if there is no alternative but to work with certain materials. As for getting more out of less, which was sound thinking with regard to the future, it will be very difficult to mould plastics and metal together because of various problems of contraction and the like. It might only be possible to use conventional materials, albeit with a more refined measure of control.

Mr Iredale agreed that this was true, but hoped that solutions to the problem could be found. There is no reason to confine ourselves to the limitations of present-day man-made materials; others may be evolved to overcome problems as they arise.

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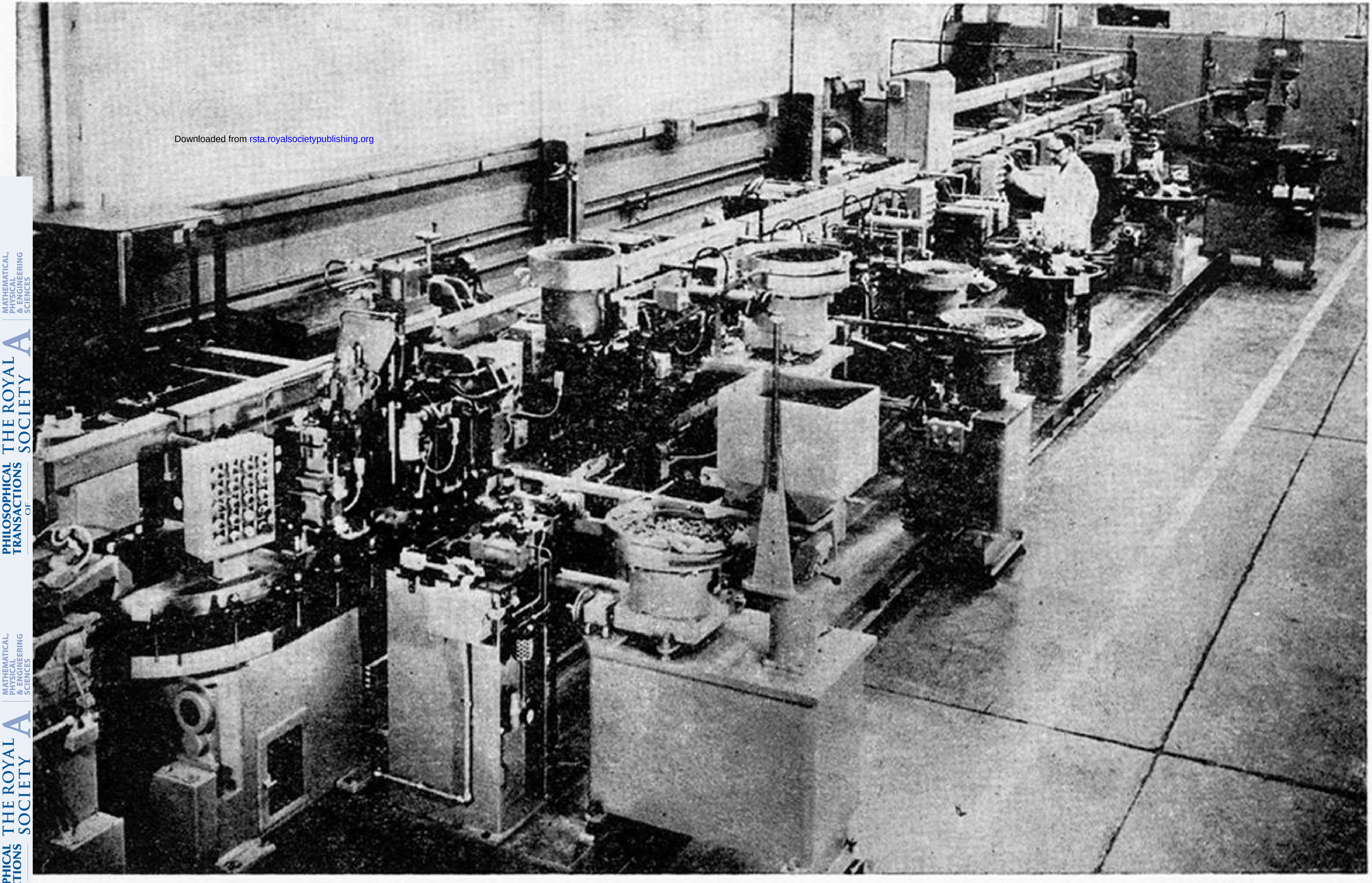

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IGURE 8. Supply modules in this Swanson Erie computer monitored assembly system feeds optional sub-assemblies into a 'demand module' to produce eight different models of a valve for automotive braking systems.