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Commission statement on advanced manufacturing equipment

Reasons and objectives

This paper has been written in response to the request made by the Ministers for Industry at their meeting in Paris on 18 May. It follows on from the Commission's statement on the machine-tool industry of 8 February 1983[1] and takes into account the experience of the Esprit programme which includes a section devoted to computer-integrated manufacturing.[2]

The paper covers the field defined by the French word *productique*, which was on the agenda of the ministers' discussion and which refers to the integrated automation of production processes that has been made possible by the application of new technologies and advanced manufacturing equipment arising from the microelectronic revolution.

The detailed implications of the automation of industry, taking into account the respective roles of economic actors and public authorities, are examined in the supporting document: 'Advanced manufacturing equipment: situation and prospects', which follows the present statement.

The production of advanced manufacturing equipment is in itself a major issue for the Community, both because of the leading-edge technologies involved and of the need to maintain European competitiveness in the key sector of capital goods.

However, its strategic importance is far larger, as the use of advanced equipment is a potential source of spectacular improvements — sometimes by orders of magnitude — in the productivity of user firms, in particular because of the increased period of use of this equipment (going towards 24h/24h). It introduces flexibility into large-scale production and for the first time allows automation of smaller batch production. In particular its use speeds up the production process (reduction of work in progress) and enables a faster response and adaptation to the market (reduction of stocks, securing of markets). It should equally be noted that this process of automation is not limited to production as such, but also integrates upstream and downstream functions, notably design (computer-aided design or CAD) and management (marketing, management and planning of production, distribution, etc.).

At present metal working, processing and assembly industries such as automobiles and aerospace play a central part in industrial automation. However the whole of industry is concerned, and the parameters in which traditional industries such as textiles, clothing and foodstuffs operate are undergoing fundamental changes. The driving role of information technology (IT) should also be noted in this investment process. This process of automation is made possible by IT and also gives rise to an accelerated expansion of the IT sector. The challenges and problems go far beyond any narrowly defined sectoral limits and concern both so-called leading edge and so-called 'mature' industries. In the longer run, the competitiveness of European industry and thus its world ranking is therefore at stake.

In the face of the on-going changes, the economic actors — i.e. enterprises and workers — must bear the main responsibility for responding to the challenges raised by the radical change in the European industry's operating conditions.

Nevertheless, public authorities at national and also at European level have their part to play in the changes that are vital if European competitiveness is to be maintained, for they are responsible for this economic environment and for creating framework conditions that enable economic agents to overcome the new challenges. Clearly, the Community can and must make a significant contribution in this area. Thus the creation of a European industrial area is essential, as it will stimulate competition in a unified continental market, as is further monetary and fiscal integration.

Standardization in the area of advanced manufacturing equipment

The benefits of the use individually of different items of equipment is considerable, but it is their

[1] Bull. EC 2-1983, point 2.1.26.
[2] OJ L 67, 9.3.1984; Bull. EC 2-1984, point 1.3.1 *et seq.*

integration into automated systems that allows full realization of their potential. The resulting benefits do not simply add up but increase exponentially.[1]

It is in this context that standardization is so important. The possibility of linking the various items of equipment and islands of automation becomes one of the key aspects of any automation strategy. For this it is vital both to promote design rules and systems architecture[2] giving rise to a framework of reference and to standardize the interfaces between the various elements making up automated systems.

The analysis demonstrates that modular standardization is involved because the elements to be standardized are not only individual items of equipment but also the different functional modules making up these items of equipment. This is related to the variety of technologies involved as a result of which standardization allows of a significant potential for specialization, increased production runs and therefore cost reduction (learning and scale effects).

Thus, there are two areas of impact of standardization. From the user's point of view it permits the integration of the various elements in automated systems allowing them to draw full benefit from automation. From the point of view of producers it provides a base from which firms can lower their production costs provided that they can achieve production on a continental or even a world scale.

This demonstrates the importance of standards which have the widest possible geographical coverage. Standardization of advanced equipment is therefore a priority area for action at the Community level.

These economic considerations explain the growing importance of standardization in all industrial countries. In the US, General Motors, having found that 30-50% of the cost of all additional automation was directly attributable to equipment compatibility, has taken the initiative of imposing on its suppliers a series of specifications relating to interfaces between items of advanced equipment. These have been arrived at with seven of GM's main suppliers including IBM, DEC and Hewlett-Packard and are codified in the MAP[3] (Manufacturing Automation Protocol). The MAP is already supported by more than 100 US enterprises (including Ford, Chrysler, IBM, General Electric) and could rapidly become a *de facto* norm in the US. Moreover, the research facility of the National Bureau of Standards (Automated Manufacturing Research Facility or AMRF), which will become fully operational in 1986, will enable evaluation and testing of norms for advanced equipment in the US. In Japan MITI is financing a large experimental complex at Tsukuba (Flexible Manufacturing Complex with Laser) in which some 20 Japanese firms in this area are participating. This will certainly play an important role in laser technology in industry (manufacturing, assembly, inspecton) but it is equally based on modular standardization of equipment. In 1984 and at the beginning of 1985 the prototype complex acted as a proving ground for evaluation, experimentation and testing by the participants and will be dismantled after the results have been transferred to industry.

Despite considerable expertise in the Community, Europe remains behind in comparison with the significant Japanese and US efforts to standardize advanced equipment. The Commission's discussions with associations representing the machine tool industry have not enabled progress on standardization of interfaces, in particular because of the dispersed nature of the traditional mechanical engineering industry, which comprises a large number of firms of varying technological levels, most of which have not yet realized the importance of standardization.

It is worth emphasizing that standardization of advanced equipment differs significantly from traditional standardization in the mechanical engineering sector. It comes within the area of IT standardization and needs to be developed from the basic framework that is being set up at international level of which the OSI (Open Systems Interconnection) remains the principal example.

In the same way as for the launching of IT standardization work, it will be necessary to ensure that the initiative should take as its starting point the principal factors involved in advanced manufacturing equipment, i.e. firms (manufacturers and users of advanced equipment) that exercise an important

[1] Benefits of the order of 250% have recently been described in the specialist journal *Usine Nouvelle* (3rd quarter 1984).
[2] Work on this is already under way in the framework of the Esprit programme.
[3] The existing specifications cover only part of the interconnection levels and work continues.

role in this area through their research and innovation efforts.

In view of the fragmentation of the industry structurers and the national divisions characterizing the European scene, the Commission must take the initiative here also, as it would be illusory to rely on industry standards developing spontaneously, as is happening in the United States.

The Community role could take the form of the following three-stage procedure:

(i) with the assistance of the national administrations concerned with industrial standardization policies, the first task will be to assemble in an informal gathering at a Community level, representatives of firms which have a direct interest in the issue;

(ii) these firms must form a nucleus, which, on the basis of international work (OSI) and in the light of (and perhaps in liaison with) activities initiated in the US, and of Japanese experience, is able to formulate a work plan defining the subsequent successive steps for development of European standardization;

(iii) when this work is sufficiently advanced and objectives defined clearly, the Commission and Member States should initiate a second phase in order to define procedures and working methods which, while taking into account the particular nature of this area, bring about what is required for all standardization activity — the adoption through an open process of consensus, of genuine European standards to be applied at national level.

A particularly important aspect of the system to be designed is that relating to experiment as well as conformance testing and certification. This is the final phase of a complex and wide-ranging process of standardization.

Exploitation of European technological potential

There are a series of important national programmes for precompetitive research and automation which concern advanced equipment either directly or individually. Nevertheless it is open for consideration whether the separation of national efforts does not involve a loss of efficiency, in particular as a result of duplication, and whether it would not be worthwhile for Member States to examine, together with the Commission, means of pulling together public efforts in the Member States with a view to enhancing intra-European synergies, and making best use of the potential that exists within Europe. This would allow a reduction of the comparative advantage enjoyed by the US and Japanese programmes (better use of resources, early launch, greater industrial involvement).

A Community dimension for R&D is important insofar as joint effort at a European level allows attainment of the 'critical mass' of R&D which permits real progress. In this respect the Esprit programme is significant with regard to precompetitive research in the area of computer-integrated manufacturing.

It is in this same context that Esprit pilot projects are very important, as they will lead to the establishment of European centres of excellence favouring contacts and cooperation within the European research community, thus at the same time reducing duplication of efforts.

The Brite programme (basic research in industrial technologies for Europe), which was adopted by the Council on 12 March 1985,[1] is designed (as is Esprit) to facilitate convergence between academic and industrial circles in the area of competitive research. The programme involves a series of priority R&D areas in the field of advanced equipment and integrated industrial automation (laser technology, CAD and mathematical models, new computer-aided test methods, etc.). Moreover the Brite programme envisages pilot and demonstration projects relevant to automation in connection with soft materials. This part of the Brite programme is of particular interest to an industry such as the clothing sector. It is worth following this work attentively to see if it can serve as a model for analogous action in other areas.

At the level of the individual firm the analysis shows that an increase in R&D is essential, particularly for suppliers of advanced equipment in the mechanical engineering sector. For a traditional machine-tool manufacturer, going over to the production of numerically controlled machine tools implies multiplying by two or even three, the percentage of his turnover devoted to R&D.

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[1] OJ L 83, 15.3.1985; Bull. EC 3-1985, point 2.1.141.

In the face of the powerful strategies being implemented by large American or Japanese groups belonging to the computer, electronic and electric industries, which, in view of the increased role of information technologies, aim to be supplying all parts of the factory of the future, an increase in intra-European cooperation would seem desirable. Such cooperation could take advantage of European strengths, which are far from negligible. Among these, in the first place, is European expertise in the mechanical sector. In fact, at the current stage of automation the in-depth knowledge of the processes to be automated is a necessary criterion for success, as is demonstrated by the fact that it is machine-tool manufacturers that have installed the majority of flexible manufacturing systems (FMS) during the last two years. In this context the objective of cooperation should be the drawing together of European industry, notably the electronics, computer, electrical and mechanical sectors.

In order to encourage such cooperation and in particular to dispel the legal uncertainty surrounding European cooperation the Commission adopted on 19 December 1984, a regulation exempting most[1] research and development agreements up to the stage of joint industrial exploitation of the results of such R&D, from restrictions under the Treaty of Rome.

Finally it would be opportune for the Commission and Member States to examine the means of improving contacts and increasing reciprocal exchanges of information between the various firms, institutions and research centres engaged in R&D on industrial automation.

Structural and financial aspects

The introduction of advanced equipment and the progressive automation of industry is causing important changes to the underlying economic structures.

Insofar as mass production is concerned, classical automation using rigid production lines is giving way to a more flexible automation which enables profitable production in smaller batches and is therefore leading to a process of 'dematurity' in an industry such as the automobile industry, long considered as mature. The traditional labour-intensive industries are liable to become technology and capital-intensive leading to changes in the pattern of international trade. Large firms can gain greater flexibility and their central management is able to react more rapidly to market signals; this reduces one of the main advantages of smaller firms, which has been their greater flexibility. Product innovation is accelerated and the life cycle of products is correspondingly shortened.

These changes also affect suppliers of advanced equipment. The competitive position of European firms active in this sector is often fragile, not because of a lack of technical know-how, but because they have neither the volume of production (linked to standardization) nor the automated production methods[2] of their competitors and are therefore seriously handicapped through higher costs. In order to overcome this handicap European firms will in many cases have to increase substantially their investments as much in equipment as in development of new products in order to cope with international competition. This is particularly true for firms belonging to the mechanical engineering sector which still contains too large a number of traditional small firms producing one machine at a time. The future seems bleak for those which cannot adapt.

Industrial automation requires significant investment on the part of users and producers in order to replace traditional equipment. Even if, in terms of productivity, new equipment is capital saving, its purchase can pose significant financial problems (particularly of cash-flow) to firms because of the large up-front investment before there is any pay-back. Moreover traditional financial criteria do not take into account strategic advantages of advanced equipment, not those that are hard to quantify (how does one value a halving of delivery time?). This makes access to external finance more difficult.

It is in this industrial and financial context that Europe has seen a rapid growth of State aids for automation over the last two or three years. This

[1] On condition that the cumulative total of the shares of the Community market held by the parties involved does not exceed 20%.

[2] While it is true that advanced equipment allows smaller batch production, a minimum volume of production is nevertheless necessary.

moreover helps to explain the acceleration of diffusion of advanced equipment in industry in the Community. Thus with an average rate of growth of over 40% during recent years Europe's robot population is now larger than that of the US.

If in certain cases State support can play a positive role in anticipating the improvement in profitability of advanced equipment, thus facilitating the learning process for firms and allowing them to surmount cash-flow problems, the danger of distortion of competition must however be underlined. The Commission intends to be particularly vigilant in this respect. Moreover, the emergence of an 'aid mentality' is to be feared. This would run directly counter to the objectives pursued by governments. The diffusion of advanced equipment and the development of industrial automation would then risk being determined by the availability of public funds rather than the dictates of the market.

There is therefore a need to consider whether public support is efficient and in particular whether the direct sectoral interventions of States are not in danger of inhibiting rather than accelerating the required industrial adjustment by artificially preserving inappropriate and obsolete economic structures. This adjustment depends on the convergence of a series of complex structural changes which can only be carried out at the level of the firm and the workforce and not by the State.

It is for this reason that preference must be given to measures of a general character – such as support for the take-up of equipment by SMEs – which leave the economic actors entirely free to make their own decisions.

Moreover even if taken individually Member States' aid programmes are at a lower level than those of the US or Japan, it appears that the volume of aid being given in the Community as a whole is high. The impression is that European efforts are not fully efficient. One explanation is probably the national divisions in the Community. When large investment projects in European countries benefit from government support, the firms involved are almost always either of national origin, or come from outside the Community.

There is therefore scope for reflection on the types of support that are efficient and on the best way of making full use of the European dimension, both as regards the private and public sectors. Some thought might be devoted to the possibility of encouraging joint projects from firms belonging to different Member States, to enable them to put together their varied capacities and to obtain the financial and organizational size that is too often lacking in Europe.

Human resources

The dissemination of advanced equipment could potentially lead to a considerable reduction in employment in industry and particularly in the manufacturing sector. In overall terms, the effects of automation have up till now been relatively unimportant. This is probably related to the fact that, up till now, advanced equipment has generally been introduced piecemeal with a fairly low degree of integration. As gains in productivity increase substantially with the integration of advanced equipment, it seems likely that the impact on employment will follow the same path. Consequently, the pace of redundancies is likely to speed up considerably in manufacturing industry when the integration process really takes off. At the same time, it should be noted that the job losses caused by advanced equipment will mainly affect companies not installing such equipment, whose market shares will dwindle as their competitiveness declines.

It would be wrong to conclude that industrial automation will necessarily cause large-scale unemployment. The production of advanced equipment itself will create a certain number of jobs. Some tasks, such as equipment maintenance, will be contracted to outside firms and thus transferred from the industrial to the service sector. The greatest source of jobs, however, is likely to be the expansionist effect of the gains arising from advanced equipment on the whole of the economy, and particularly on the development of services.

In order to achieve the redeployment of the workforce this implies, the European economies will have to see through a major transformation in qualifications and in the sectoral (and in all likelihood geographical) distribution of employment.

This change in qualifications at all levels is undoubtedly one of the greatest challenges raised by the introduction of advanced equipment. Achieving it requires a massive effort in the field of training and education throughout the Community. There is already a shortage of certain skills, in particular of technicians and engineers in 'mechatronics', which could act as a bottleneck for the further dissemination of advanced equipment. This could in turn affect European competitiveness, especially in the case of SMEs, which do not have the means to set up internal retraining programmes. It is essentially up to Member States and their regonal and local authorities to implement the necessary measures, but the Commission can promote contacts and exchanges at European level, and generally help to stimulate action. More specifically, the Commission has proposed setting up 'partnership programmes' which correspond very closely to the needs that have been identified in the field of advanced equipment, in particular as regards the vital need for more multi-disciplinary qualifications.[1]

The social partners have a crucial role not only as regards qualifications, but for all of the changes that will be brought about by automation, notably in the organization of work. In this area, increased flexibility is essential for maintaining competitiveness. Without replacing the necessary discussions at the level of firms and Member States, the Commission intends to play its part fully in stimulating the dialogue between social partners at European level.

Information on the evolution of industrial automation

Advanced equipment is an area of constant and rapid change. It is difficult to assemble consistent and comparable information in this field and, given the need for the decision-makers (industry and public authorities) to know how the situation is developing, the Commission proposes to entrust independent institutes in different Member States with a multiannual contract for coordinated annual reports, using a common methodology, on advanced equipment and the evolution of industrial automation.

[1] COM(84) 6 final (January 1984): 'Technological change and social adjustment'; Bull. EC 1-1984, point 1.3.1 *et seq.*; Doc. V/1523/84: 'Industry-university cooperation and technological change: its role in the creation and development of firms'.

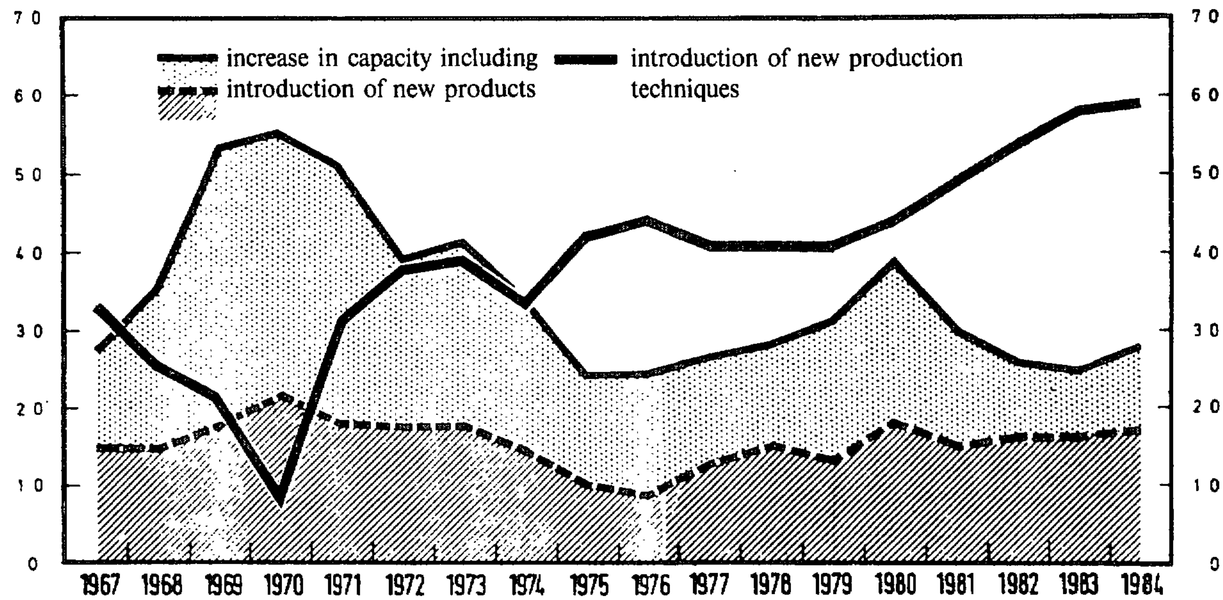
Situation and outlook

Introduction

The emergence of advanced manufacturing equipment as a result of the convergence of mechanical engineering and microelectronics is leading to important industrial changes in permitting, for the first time, automation which is both integrated and flexible, of production processes.

The installation of this equipment and above all its integration into automated systems allows of highly significant gains for user firms, not only of productivity but also in terms of stock levels, work in progress as well as other aspects, more difficult to quantify, such as quality. The main impact of this advanced equipment is therefore at the production process stage. The graph below demonstrates this in the case of the Federal Republic of Germany, showing a significant increase in investment by German firms in the area of new production techniques.

Destination of investment by processing industry in Germany
Percentage weighted by company turnover of investment destined for:



Source: IFO.

At the current stage processing and metal-working industries, such as the aeronautics and vehicle sectors, are at the centre of this veritable industrial revolution which particularly involves manufacturing industry (defined here as discontinuous process industry[1] – a concept covering manufacture in series, large and small) which represents some 60% of industrial value-added in the Community.

It is indeed a revolution since it involves the changeover from an economy structured on mechanical engineering principles (mass production, product uniformity and a limited degree of independence and intelligence in the various stages of the process)to an economy featuring flexibility, the capacity to react rapidly to market trends, product adaptability and low-cost distributed intelligence in the production process. These results cannot be achieved merely by grafting electronics onto existing machinery; there must be a genuine merger of mechanical and electronic technologies involving a completely new industrial culture marked by a comprehensive and multidisciplinary approach to production problems.

This technological revolution calls for a radical change in the economic conditions within which companies operate and in the organization of work within the firm. In addition to the technical ability to solve production problems, the economic and human aspects become of vital importance.

[1] See Explanatory Note 1, p. 58.

Advanced manufacturing equipment embraces advanced machine tools, industrial robots, flexible manufacturing cells, systems and transfer lines, mechanical handling, transport, automatic inspection and warehousing as well as computer-aided design and manufacture, local communication networks and industrial computing in the widest sense of the term. It is difficult to illustrate the situation by statistics but by cross checking various sources of information[1] a relatively consistent picture of the overall situation can be obtained. It shows that the existing Community market for this equipment — intended for discontinuous processes — may be estimated at close to 8 000 million ECU a year. The market is growing rapidly and, while it is risky to state an overall rate of growth, annual increases of 25% or 30% — and even more — are currently mentioned for certain items of equipment.

The analysis below is divided into three parts:

(a) The factors involved in technological development (including standardization);

(b) The structural and financial implications for companies;

(c) The human resources.

This examination of the issues is based mainly on the content of the three annexes. Annex I reviews the various types of advanced equipment (for each type of equipment — definition, economic return, extent of diffusion, situation of European producers and outlook for demand) in order to arrive at an overall picture of integrated automation in the factory of the future. Annex II attempts to provide details of State aids in the four largest Community countries and in the US and Japan. Finally Annex III contains statistical tables and background figures.

Factors involved in technological development

The content of Annex I brings out clearly the importance of technological development and shows that, despite the frequent references to the technological gap between Europe and the United States or Japan, Europe does not lack know-how in the field of advanced equipment, the problem being to exploit this know-how in industrial and economic life.

Main lines of technological development

Integration: Since the integration of various types of advanced equipment can increase productivity several-fold, the possibility of connecting them together, i.e. the existence of compatible interfaces, is of vital importance for the future success of the automation process. The importance of this is not yet fully realized by many European companies which are still introducing individual items of equipment and have not yet tackled the question of integration, but compatibility requirements are bound to become increasingly important as advanced equipment becomes more widespread. So far it is really only the major users that are acutely aware of these problems and therefore it comes as no surprise to learn that General Motors has taken the most significant step in recent years.

When GM found that only 15% of the 40 000 programmable machines it owns were capable of communicating outside their own processes and that 30-50% of the costs of any additional automation were directly linked to the compatibility of equipment, it decided to require all its suppliers of advanced equipment to meet a series of interface norms for both software and hardware known as MAP (Manufacturing Automated Protocol). The norms are developed by GM in cooperation with seven of its main suppliers, including IBM, DEC and Hewlett-Packard.

Modularity: The existing or potential importance of modularity in reducing costs is demonstrated on several occasions in Annex I. The principle of modularity is of almost universal application in advanced equipment — whether at the level of CAD software, the different parts of an FMS or the functional components making up a machine tool or a robot — and at the same time is indissolubly linked to standardization which allows the necessary production volumes to be attained. Hi-fi equipment provides an interesting parallel: a few years ago record players were sold in the form of a single unit containing all the required functions. With the development of more complex technologies modular units swept the market and it is now

[1] See Explanatory Note 2, p. 58.

easy to buy tuners, amplifiers, turntables and recorders of different makes in the form of modules that can be connected together. Consequently modularity also goes with specialization. One point of importance: it is the definition of the modules that allows identification of the interfaces between the different modules and hence the level at which compatibility must be ensured.

Reliability: One of the most immediate problems in installing ever more complex and more integrated plant is reliability, an essential characteristic if machines are to be able to operate without interruption over long periods. In the case of machine tools the rate of utilization for conventional machines is close to 60%, whereas in automated systems it is as high as 80-90% according to Kearney and Trecker. It is therefore generally necessary to review the design of machines to be incorporated in a system. These machines will increasingly be equipped with instruments to measure tool wear, diagnose failures and even avert them by giving warning of malfunctions before they bring the system to a standstill. This is of great importance because it is much more difficult for a technician to trace a fault in a complex system than in an isolated machine (in addition there is a shortage of qualified technicians – see section on human resources). At present hardware and software reliability problems are perhaps the main drag on the cost effectiveness of complex systems and tend to put off potential purchasers.

Intelligence: The concept of 'intelligence' is applied mainly in the field of robotics. The JIRA (Japanese Industrial Robot Association) is of the opinion that intelligent sensor-based robots with recognition facilities which accounted for 9% by value of Japanese robot production in 1979 will increase their share to 23% in 1990. In 1982 the *Financial Times* estimated that in Western Europe this share[1] would reach 11% in 1986 starting from almost nothing in 1981. These robots are given intelligence by fitting them with vision and/or touch sensors and developing sophisticated software enabling them to adapt their behaviour in the light of the information transmitted by these sensors. With the steady improvement in robot vision brought about by technological progress, there is likely to be very rapid growth in vision sensors; it is estimated[2] that they were fitted to less than 5% of robots in 1984 but this will increase to over 10% in 1985. The world market[3] in vision systems is likely to grow from 800 units in 1984 to 7 000 units in 1990 and 14 000 units in 1992. In terms of cost, this means that the share of software and sophisticated electronics (sensors) will increase in comparison to more conventional components, including the mechanical side as the following table show.

%

	1980	1985	1990
% of robot population (all industries) equipped with			
– recognition system – 2D	2	20	30
– 3D	0	1	10
– vision sensors	1	10	25
– tactile sensors	2	10	20
% of robot population able to take strategic decisions	5	10	20
	1980	1983	1990
Robot control systems			
– no computer	60	28	12
– mini-computer	20	33	38
– microprocessor	20	39	50

Source: Delphi Study. SME. University of Michigan, 1982.

Although all that has been said above concerns robotics, these developments are also obviously affecting all automated production systems, which are benefiting from this increase in intelligence.

Flexibility: At all levels equipment is being developed to give greater flexibility and versatility. One example is the FMS that Citroën installed in its Meudon works in 1983 to produce prototypes of mechanical components. A very wide range of parts have to be machined in very short runs. In most

[1] Percentages not strictly comparable: in Japan they are based on a wider definition of robots (see Annex 1).
[2] *Usine Nouvelle*, 28 June 1984.
[3] *Science et Technique*, February 1984.

cases each part has to be machined differently and therefore requires a different set of tools; the number of tools increases more rapidly than the number of parts because of the need to keep spare tools in case of breakage. There are 700 tools used in this system, 600 of them being kept in an auxiliary store specially designed by Citroën and connected to the machining centres by self-guided vehicles that also carry parts between the different machines. The push for flexibility (it appears that FMSs with 1 000 tools are on the drawing board)[1] necessitates increasingly complex software and perhaps above all hardware and tooling, which aggravates the reliability problem and hence increases the risk of stoppage (factors on which cost effectiveness depends). Here the use of the laser for machining appears to be very promising since lasers can perform a very wide variety of machining functions. This has not escaped MITI: one of its major R&D projects is the Flexible Manufacturing Complex with Laser at Tsukuba. This project, which has been undergoing testing and experimentation by the groups participating in 1984 and early 1985, consists of a very sophisticated FMS built around a 20 kW CO_2 laser and incorporating automated inspection of the parts produced at the end of the process.

Unmanned operation: By combining the above improvements it should be possible to obtain a greater potential for unmanned operation allowing installations to run for long periods with a minimum of human intervention.

Development of software and data-processing capacity: As various types of equipment are examined and the main lines of technological development outlined it becomes clear that software will have to be further developed and will become more and more sophisticated thereby accounting for a growing share of the total cost of automation.

This is illustrated in the following graph which shows the cost trends for a machine-tool numerical control system.

At the same time larger information processing capacities will be required, i.e. more powerful computers and microcomputers (at the same cost), which appears to be in line with current developments. Although Europe plays a minor role in computer hardware, it does in principle have some real know-how in the software field.

Overall picture: Solutions to the various problems mentioned here already exist in many cases, at least at experimental level. What must be done is to make them applicable on an industrial scale, in particular by reducing costs. This enabled the OTA[2] to predict in a recent study the solutions to a number of technical problems relevant to automation which are shown in the following table (p. 15).

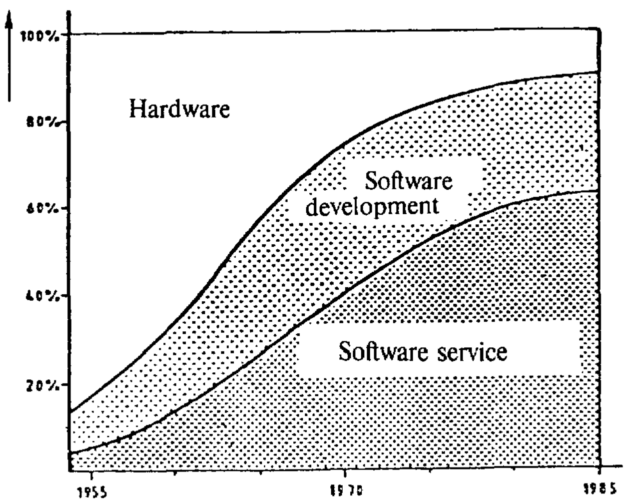
Standardization

Standardization applicable to advanced manufacturing equipment has certain special features. What is needed is compatibility standardization, often at the forefront of fast-developing technological knowledge. Standardization work in the conventional machine-tool industry underwent a complex transformation when NC machines appeared on the market. The changes likely to come about in the standardization of the most advanced manufacturing equipment are radically different from the earlier ones.

Difficulties in normalization work arise from the need to simultaneously:

(a) produce a systems architecture incorporating the different levels of communication between very complex systems and sub-systems, without which there is a risk of divergent interface arrangements;

Percentage of total costs



Source: Koch, 'Systematisches Softwareengineering für Microcomputer', *Elektronik*, special edition No 53.

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[1] *Financial Times*, 12.1.1984.
[2] Office of Technology Assessment, US Congress.

Programmable automation: a few projections on the solution of key problems

	Now (1984)	1985-86	1987-90	1991-2000	2000
1. Powerful low-cost terminals based on microcomputers for[1]:					
(a) electronic design	▲	●	■		
(b) mechanical design		▲	●	■	
2. 3D vision in a structured environment designed to simplify vision	▲ ●		■		
3. 3D vision in a complex non-structured environment			▲	●	■
4. FMS for[2]					
(a) production of cylindrical parts	▲ ●			■	
(b) metal forming	▲ ●			■	
(c) 3D mechanical assembly	▲			● ■	
(d) electronic assembly	▲ ●		■		
5. Standardization of interfaces for a wide range of computerized equipment in an integrated factory			▲	●	■
6. Computerized factories operating regularly with only a skeleton management and design staff					▲

[1] Terminals based on microcomputers are already on the market but, in the opinion of the technical experts consulted by the OTA, they are not sufficiently powerful or cheap to be very widely used.
[2] Almost all the FMS now in operation are used to machine prismatic parts (e.g. engine blocks).

▲ Laboratory solution.
● First commercial applications.
■ Widespread and easily accessible solution (requiring a minimum of specific adaptations by the customer).

Source: OTA.

(b) produce norms and detailed technical specifications guaranteeing the inter-operability of systems without having to introduce new modifications for each new commencement of operations.

Normalization in this sector comes within the sphere of new information technology and the Commission has already underlined aspects specific to such sectors and their strategic importance (see Doc. SEC(84) 796).

There is no need to repeat the detailed analysis made in that document but it seems useful to put forward a few key points concerning the standardization of advanced equipment:

Modular standardization: It is important to determine the level at which standardization should operate. The above analysis shows that it is needed at the level of the various modules making up advanced equipment rather than solely at the level of the interfaces between the different equipment. It is quite possible that eventually some manufacturers will specialize in the production of certain modules rather than, for example, complete robots, in view of the diversity of technologies involved and the very substantial cost reduction that specialization can offer.

Need for a consensus: If the standardization process is to be successful a consensus must be reached between the different parties involved (manufacturers and also users). Although the electronic industry appears to have realized recently the importance of standardization and compatibility, it does not seem that the European mechanical engineering industry which is also very widely involved in advanced equipment is really aware of the scope of the problems and prepared to put in the necessary effort.

Verification of standards: Verification and certification may well give rise to major material problems. Mention should be made of the significant work of the National Bureau of Standards in the United States which is setting up an 'Automated Manufacturing Research Facility' (AMRF) to serve as a test bench for standards.

The scale of the problems involved in the standardization of new production facilities must also be borne in mind.

The introduction of new production facilities calls for the development of a software unit similar to the operating systems of computers but even more complex. The system has to operate in real time with extraordinary reliability. It is fully distributed, the peripherals it has to manage are themselves extremely delicate systems and the whole has to be meshed into industrial manufacturing processes in which man has his part to play so that allowance has to be made for an environment that cannot be 100% automated.

Many examples show that progress here depends heavily on the alliances formed between the industries manufacturing and using this equipment. But differences between users and manufacturers are becoming blurred: the speed of innovation and problems concerning the industrial ownership of the new software products and interconnection diagrams are factors that can lead to technical harmonization activities which can be promoted through mechanisms of consensus and public enquiry resulting in a process of European standardization.

Standardization cannot be confined to the electronic and software aspects but must at the same time cover the mechanical aspects of the different interfaces.

In the face of this situation European manufacturers will have to decide on their own strategy, bearing in mind the numerous world links in manufacturing circuits (for example, the motor industry). If standardization problems are not tackled rapidly, the prospects of reaching an agreed solution will dwindle and alternatives will no longer be available. The difficulty a heavy plant-based industry has in grasping this situation and appraising the future in the light of the new software and interconnected systems architecture must not be underestimated.

Research and development

The Esprit programme[1] has a section on computer-integrated manufacturing, the aim of which is to define the principles and basic rules governing the design of integrated manufacturing systems and to develop systems architectures enabling users to adapt to computer-integrated manufacturing at their own rate and in accordance with their own requirements, while ensuring that the development programme is equally applicable to short and long production runs. The specific objectives of the Esprit programme in this context include systems architecture, CAD/CAE, CAM, machine control systems, and sub-systems and components (including sensors).

There are also plans to set up pilot projects under Esprit on the basis of a preparatory study so as to focus the European R&D effort while at the same time serving educational and demonstration purposes.

The Esprit programme is now moving into its operational phase and, bearing in mind the importance of software as already demonstrated, the responses to the Esprit calls for proposals in this field leave something to be desired (software technology, like computer-integrated manufacturing, is one of the five priority topics of the programme). This is perhaps a sign that the European industry has not yet fully grasped its significance.

Esprit focuses on precompetitive research but an examination of the main lines of technological development has also shown the importance of applied R&D, a field in which the links between industry and the research world are of crucial importance.

The Brite programme which was adopted by the Council on 12 March 1985[2] concentrates on this link and focuses on many of the key points highlighted in the examination of lines of technological development, in particular:

(i) reliability, wear and deterioration of materials, components and assembled products;

(ii) laser technology and other new methods of metal shaping and forming;

(iii) new testing methods including computer-aided testing in the manufacturing process;

(iv) CAD/CAM and mathematical models.

[1] OJ L 67, 9.3.1984.
[2] OJ L 83, 15.3.1985.

Moreover the programme envisages pilot and demonstration projects on automated handling of soft materials and articles manufactured from such material, their automated assembly and transformation into finished products and the integration of these techniques in order to attain automated and flexible manufacturing. The clothing industry is particularly interested in these projects.

In parallel there are a number of national programmes directly or indirectly bearing on the advanced equipment sector, such as the Fertigungstechnik programme in the FR of Germany, the Alvey programme in the UK, the productique programme in France, the Technologie Meccaniche programme in Italy, or the Flair programme in the Netherlands. Although there is often substantial funding for national programmes, Esprit and Brite nevertheless remain significant in terms of precompetitive R&D and the number of participants induced to cooperate on Community-wide projects.

It is also worth pointing out that there are a number of institutes, universities and other organizations in the Community which undertake R&D in the advanced equipment area. It is perhaps worth considering whether the fragmentation of the work and the lack of coordination at a European level is not leading to under-exploitation of the considerable potential present.

Structural and financial implications for companies

Although technological development factors are of vital importance for the automation process, it is a fact that manufacturing and user firms are far more interested in the short term, as Tables 1 and 2 in Annex III show: technological problems fall far behind economic problems and the difficulties in obtaining skilled personnel stemming from the introduction of microelectronics.

Although the companies themselves regard the financial aspects as the most important of these economic problems, the analysis conducted in Annex I demonstrates a number of features that could usefully be summed up before going on to a more systematic analysis of their structural and financial implications.

First of all, the installation of advanced equipment, whether machines or systems, is even now capable of substantially improving company profitability even if the technical productivity coefficients sometimes have to be viewed with caution. Even though the most complex FMS-type equipment often only shows a low financial return at the present time, one must not lose sight of the dynamic cost-reducing factor introduced by technological progress nor the often crucial importance of advantages difficult to quantify such as the reduction in design, manufacturing and delivery times when this equipment is used. However, these improvements can be obtained only at the cost of a very much higher initial investment than is needed for conventional equipment.

This high initial investment is a factor to be considered not only by users but also by suppliers of advanced equipment who have to put in a substantial research and, above all, development effort in order to perfect this equipment and who also have to modernize their own manufacturing methods in order to stand up to international competition, and especially in order to attain modular standardization of their equipment.

This modular approach (applicable to all advanced equipment) combined with learning effects can bring about a spectacular reduction in production costs once the market reaches a certain size. That is why considerations cannot be confined to national markets or even the European market. Arguments must be based on the world market. Much of European production is too fragmented as it generally concentrates too much on the domestic market.

In many cases European suppliers of advanced equipment are still in a precarious position. Often the reasons lie not in a lack of technical know-how but in the difficulty of adapting to the new economic environment brought about by the microelectronic revolution, which the engineering industry in particular appears to find hard to accept.

As far as the spread of advanced equipment is concerned, leaving aside CAD which is lagging well behind, Europe has made up a greal deal of ground on the USA and Japan since the beginning of this decade, partly as a result of government support. This is particularly clear in the field of industrial robots and complex systems of the FMS type where installed capacity in Europe now exceeds that of the

United States although overall Japan still has a lead. Generally speaking high and sustained growth in demand for the various types of advanced equipment is predicted at least to the end of the decade.

Financial aspects

European companies tend to see investment in advanced equipment mainly from the aspect of cost reduction, while their American and Japanese rivals are far more interested in the advantages of flexibility, customer service, product improvement, etc. This difference in approach reflects the generally defensive attitude of European manufacturing industry to these new technologies, and at the same time shows that in general it has not yet fully realized the advantages offered by advanced equipment and above all integrated automation.

Investment in automation differs greatly from traditional investment as it is a decision that involves the strategic reorganization of the companies' activities and structures, although it brings a number of benefits that can be quantified in material terms such as:

(i) improved productivity of machines and labour;

(ii) reduction of work in progress and stocks;

(iii) savings in materials by reducing scrap;

(iv) reduction in defects;

(v) elimination of costly prototypes.

Many of its advantages are more difficult to evaluate in financial terms:

(i) improvement in product quality and performance as a result of better design, greater manufacturing accuracy and reduction in human errors;

(ii) an often spectacular reduction in the time required to design a new product;

(iii) an equally spectacular reduction in manufacturing times;

(iv) an improvement in customer relations — for example, late deliveries can be avoided.

It is to be feared that the methods used by many firms to evaluate investment do not even take into account the easily quantifiable advantages of reducing stock levels even though it is often here that the major savings can be made. Clearly, then, it is even more of a problem to take into account advantages that are difficult to evaluate.

The experience gradually acquired by the user has a major influence on the advantages he is able to derive from automation so that, unlike conventional investment, the profitability of advanced equipment tends to improve with time.

Investment in advanced equipment therefore throws up a number of problems:

(i) purchase of advanced equipment requires a sizeable initial investment as for example with an NC machine tool in comparison with a traditional machine (Annex I). Even if, overall, the return on capital invested is higher the need to employ significant funding at the outset can pose real problems especially to smaller firms;

(ii) conventional methods of assessing financial returns on the investment are no longer fully valid because of the existence of non-quantifiable advantages that increase with the degree of automation;

(iii) to complicate the matter, the various types of equipment and systems offer fairly different levels of financial return;

(iv) this type of investment calls for a longer-term economic view than is normal in Europe because of the need to integrate the advanced equipment and the importance of learning effects (cost effectiveness improves throughout the learning period).

All this puts difficulties in the way of European companies, especially the smaller ones. The situation as regards self-financing in European industry is not generally very good in comparison to Japanese and American firms. As regards access to outside financing, leaving aside problems specific to one or other of the Member States, there are analogous difficulties relating to financial evaluation criteria in particular to those concerning long-term strategic investments.

Although the use of advanced equipment in isolation or simple flexible manufacturing cells is without any doubt already profitable today, even this type of elementary automation comes up against financial problems, as is demonstrated strikingly by a recent survey on investment by small businesses in Italy.[1] It compares the investment plans of these

[1] Boston Consulting Group.

firms over the next five years with the level of investment they would consider ideal. Overall the level of automation (use of advanced machine tools and flexible manufacturing cells) in the latter case would be almost twice as high.

There remains State support which, as Annex II shows, takes various forms in most industrialized countries. When this aid helps directly or indirectly to finance investment in advanced equipment, it may be said to have the advantage of implicity taking into account the strategic nature of the investment and its non-quantifiable benefits. By anticipating an amelioration of profitability thresholds it also encourages the use of more complex equipment and systems with which experience must be gained today if the even more complex and more integrated technologies of tomorrow are to be mastered. Nevertheless these direct investment subsidies must be regarded with some caution. Not only is there an obvious risk of distortion of competition with all the dangers which that brings, there is also the danger of artificially encouraging certain investment projects or certain types of equipment without at the same time creating the environment and basic conditions essential to complete the automation process. This, as the following analysis shows, depends on the convergence of a number of structural changes within companies. These may well have been impeded rather than accelerated by direct state support which all too often helps to keep non-viable industrial structures going.

Another comment on the effectiveness of the aid is called for. Even though a realistic international comparison of aid poses almost insurmountable difficulties, a detailed examination of the different national systems in Annex II shows a rapid extension of aid programmes in the European countries. If the national programmes taken individually are clearly on a smaller scale than those of Japan and the US, the totality of programmes is certainly comparable with Japanese and US efforts.

At the same time there is an undeniable impression that funds are spread too thinly when the different European programmes are compared with those of the United States and above all Japan. In the United States aid is essentially concentrated on military or space objectives[1] – which does not mean that it has no civil spin-off – whereas in Japan support activities are well structured to meet coherent industrial objectives and form part of a policy bringing together the main firms concerned and covering all the aspects involved. Robotics provides a striking example. MITI is developing a number of measures and activities designed to stimulate both production and demand. On the production side there are loans at reduced rates for the development of robots, the setting-up – at the instigation of MITI – of JIRA (Japanese Industrial Robot Association), the financing by MITI of a research programme on robot standardization, the formation of a research association (ATRA) financed by MITI and even a wider definition of robots to encourage technological progress by manufacturers of fixed manipulators (see definition of robots in Annex I). On the demand side there are loans at reduced rates for the purchase of robots, financial support by MITI for Jarol (a robot leasing company set up by JIRA) and credit insurance systems. All these measures fit into the more general context of the MITI improvement programmes and the law for the promotion of the engineering, electronic and software industries (1978-85). In comparison, European aid programmes appear in many cases to have been set up in too fragmented a manner without any great effort towards consistency at a European or even a national level.

Structural aspects: users of advanced equipment

The first point to be made is that in one way or another advanced equipment is of relevance to almost all manufacturing firms.[2] Here the importance of compatibility of equipment must be emphasized yet again not only because of the many benefits to be gained from integration but also because the lack of interface standards can be a major deterrent to the purchase of advanced equipment by users, especially in Europe where the shortage of capital means that the automation has to be a very gradual process in many firms. For them the introduction of such standards could have a major psychological impact in encouraging them to go ahead. At a more general and more macroeconomic level the increase in the productivity of machines and the capital-saving effects referred to above give an improvement in the productivity of capital, which is a basic reversal of the downward trends recorded for more than 20 years. It is not going too far to expect integrated automation to provide the driving force to extricate the economic

[1] In this context it is worth noting that President Reagan has just vetoed a Federal programme of civil R&D in the industrial automation sector.
[2] See Explanatory Note 3, p. 58.

machine from the current crisis. At company level, however, this process will bring about a number of changes in the major balances underlying the industrial fabric of our societies.

No longer 'mature' traditional industries: The new possibilities of automating small-batch manufacture may well affect most radically the 'mature' industries which in fact have the greatest potential for improvements in competitiveness. Traditional industries such as clothing or furniture can progress from semi-craft production to partially or even extensively automated manufacturing. Labour-intensive industries will thus become capital-intensive ones in which factors governing competition are no longer labout costs but technological innovations, speed of response to the market, etc.

Changes in trade patterns: This upsetting of production factors will modify comparative advantages in a way that could bring about a radical transformation of international trade patterns, especially *vis-à-vis* the low-wage cost countries. The motor industry is a particularly significant example of the impact of loss of maturity on trade patterns. Only two or three years ago it was widely recognized and accepted by manufacturers that the car was a mature product in which technical innovation would play no more than a minor role and for which the most important factors were the length of production runs (on conventional transfer lines) and the possibility of writing off capital investment over a large production volume. This led to the concept of a world car to be marketed globally, the different components of which would be manufactured in different parts of the world on the basis of labour costs, the technical sophistication of the component concerned, the characteristics of the manufacturing process for the component, etc. so as to benefit from all the possible comparative advantages and economies of scale. This theory has been challenged by flexible automation which, as already shown, greatly reduces the length of the production runs needed for automation and at the same time allows a wider variety of products to be manufactured to the benefit – at least as far as production costs are concerned – of smaller and more specialized manufacturers whose production is of a more local nature.

Flexibility of companies: Even though within the manufacturing process proper the introduction of advanced equipment shifts the balance in favour of smaller firms,[1] as is shown very clearly in Figure 2 in Annex III, this is not necessarily true at all levels. According to various surveys small companies are more inclined than larger ones to view advanced equipment solely from the cost reduction aspects. Generally speaking large companies concentrate far more on process innovations than small ones but this also has a structural explanation since the gain in flexibility is more marked in large companies. In the past they had to decentralize in order to manage their numerous scattered operations whereas integrated automation combined with the computerization of management functions now provides them (even the large multinationals)with a tool with which central management is capable of responding very rapidly to market requirements. Consequently the larger companies are potentially in a position to cut back the advantage of flexibility which until now has been the main asset of the smaller firms.

Product innovation: In a growing number of areas the use of advanced equipment is becoming essential to stay competitive not only in processes but also in products. Obviously a product such as a modern aircraft can no longer be designed without using CAD. However, advanced equipment has far greater implications for the product itself, at several levels.

To introduce integrated automation or even merely to use the standard CAD systems on the market, the user has to rethink his production processes from top to bottom, which often leads him to re-model his product as it can no longer be designed separately from the process. In this respect the aeronautical industry is a case in point. The production process is designed at the same time as the aeroplane and can represent 40-50% of the total R&D cost linked to a project. GM provides another striking illustration with its Saturn project (future medium-sized cars). From the outset it brought the teams and engineers responsible for the product together with those responsible for the process so that they could cooperate in designing the car and its production process simultaneously in order to optimize not only the vehicle performance and characteristics but also its manufacturing method (use of materials, assembly operations, etc.) and consequently its production cost. The link between process and product is sometimes less direct but no less important, as is shown by the European machine-tool manufacturers themselves.

[1] Although of course a minimum batch size is still necessary even for flexible automation.

Only by using automated production methods can they cut their costs sufficiently to stand up to international competition, but to introduce these methods they have to move from customized manufacture to modular standardization and a minimum production volume. Here again, in product design and innovation, the balance is shifting in favour of companies large enough to use CAD integrated with automated production methods and capable of fully exploiting the resultant speeding-up of the product cycle. It is now estimated that a delay of 12 months in the development of a product leads to a 50% loss in the revenue obtained from the sale of the product throughout its life.[1]

Smaller stocks: Optimum use of advanced equipment leads to a substantial and widespread reduction in stocks of materials, components and finished products held by manufacturing companies. Here a real revolution in industrial thinking is under way with a tendency to take as a model the Japanese practice known as 'Kanban' in which all deliveries to the factory arrive just in time to be fed into the production cycle. This means that relations between the company and its suppliers must be reorganized (they often need to be located close to each other), and a structure of stable social relations must exist.

Subcontracting: Here developments are likely to be complex. On the one side the introduction of overall product design, the more integrated management of the manufacturing process and the additional production capacity resulting from the installation of advanced equipment may tend to reduce subcontracting. On the other side, the complexity and growing diversity of the technologies involved and the difficulty, especially financial, in carrying on all the necessary development activities simultaneously, encourage companies to turn to outside suppliers. In actual fact these trends are not in conflict and the large companies are likely to step up their own production of integrated components required in numbers exceeding a certain threshold while making increased use of subcontracting for more complex items often requiring specific technological development or insufficient in number to be incorporated in a largely automated overall manufacturing process.

Structural aspects: suppliers of advanced equipment

Suppliers: These are firms in the engineering, electrical, electronic and computer industries or systems houses which put together various components from different sources around a software development capacity. The firms concerned in the engineering industry are either the traditional producers of capital goods, i.e. machine tool manufacturers, or major users such as the motor industry whose role in robot manufacture has already been mentioned.

R&D, reorganization of production and financial resources: In the engineering industry above all, the production of advanced equipment calls for a substantial increase in the R&D effort. To give a practical example, it is estimated[2] that the changeover from the manufacture of conventional grinding machines to NC grinding machines requires the share of turnover spent on R&D to be increased from 4-6% to 15%. This substantial increase in applied research[3] in turn requires a minimum level of financial resources. Capital availability is of even greater importance for the investment and basic reorganization needed to secure economies of scale associated with modular standardization and the learning effects typical of information technology. When the increase in the average value of the product is also taken into account, it is obvious that the development of advanced equipment encourages the concentration of production in the larger firms.

Strategy of the major American groups: The very extensive effort put in by groups such as GE, Westinghouse and IBM to ensure that they are able to supply all the components of the 'factory of the future' must be viewed in this context of the necessary increase in company resources. The efforts being made include R&D, investment, the take-over of companies specializing in the manufacture of certain types of advanced equipment, and the conclusion of licence and cooperation agreements for which these multinationals enjoy a particularly favourable situation because of their size and geographical spread. By marketing all types of advanced equipment these firms are in a position to develop internal compatibility norms, an important selling point in the eyes of users, which (in the absence of generally recognized standards) have the advantage — from the suppliers' point of view — of

[1] *Source*: *Financial Times*, 19.9.1984, 'New product development — a vicious race to get ahead'.
[2] Boston Consulting Group.
[3] Even though Europe holds its own in international comparisons of R&D expenditure, it should be borne in mind that these include basic research which accounts for a larger share of the European effort.

forcing customers to remain loyal to them. However, these ambitions are thwarted by General Motors' recent decision to require all its suppliers of advanced equipment to adhere to the MAP (see p. 12), since the MAP is sooner or later likely to become a *de facto* norm, at least for the American industry, especially as it is supported by Chrysler and Ford has just emphatically endorsed it (the Automated Manufacturing Research Facility of the US National Bureau of Standards could play a significant role in the verification of standards). At the same time mention should be made of the efforts of major users such as GM or MacDonnell Douglas to become suppliers of advanced equipment. These are a logical consequence of the close interaction between suppliers and users during the design installation of advanced equipment. As a result the dividing line between suppliers and users is tending to become blurred. For example, GM entered into association with Fanuc to set up in the United States the firm GMF which rapidly became the leading American manufacturer of robots. In June 1984 GM took over EDS (Electronic Data Systems), a company specializing in the reorganization of computerized systems, so as to implement the MAP. GM has recently obtained holdings in three robot vision companies and in another company specializing in artificial intelligence. Unlike GE or Westinghouse, GM started life in the mechanical engineering industry. This is a point worthy of mention because it might seem that the growing importance of electronics and software would give the advantage to firms from the electrical or electronic industries. However, this does not appear to be the case as these firms apparently find it difficult to make the move from their relatively clean environment to the factory floor where equipment is exposed to far harsher conditions. Two of the three contracts for FMS in the United States last year were won by Cincinnati Milacron which is not only the largest American manufacturer of machine tools but has also become the second largest robot manufacturer in the USA (after GMF).

Another major firm in the United States is IBM which, despite setting up a group factory automation, had until recently adopted a wait-and-see attitude. However, IBM is showing increasing interest in factory automation and, among other things, it has just concluded an agreement with Cincinnati Milacron for the supply of control systems for advanced equipment. The lesson to be learned from this analysis of the situation in the United States is that at the current stage in the development of advanced equipment a knowledge of the process appears to be a vital asset for potential suppliers. Since the engineering industry dominates demand, this gives the advantage to firms in that industry, whether they be users such as the motor industry or suppliers such as the machine-tool industry, provided they are able to acquire the essential know-how in the way of electronics and software (either by mergers and take-overs or by cooperation agreements). This does not rule out the possibility that in the later stages of the development of this market the assembly capacities acquired by GE and Westinghouse in particular will become of growing importance. One appreciable advantage enjoyed by the major groups which are themselves large users of advanced equipment is the availability not only of an in-house market but also of a test bed and field of application for the development of equipment and systems. As it takes at least a few months to install a complex system and even after that experience a further few months is needed before it can be used to its full potential, this in-house market is obviously a very great asset.

Japanese strategy: Japanese suppliers may not have announced their general ambitions as loudly as the Americans but they are nevertheless devoting massive resources to securing foothold on tomorrow's advanced equipment market, using an approach of a more cooperative nature coordinated by MITI. One of the most important projects financed by MITI is the Flexible Manufacturing Complex with Laser at Tsukuba which in addition to experiments on the use of the laser will be developing standardized functional modules[1] with the participation of many large Japanese firms (Mitsubishi Electric, NEC, Toshiba, Fanuc, Matsushita, Mitsubishi Heavy Industries, Ishikawajina-Hasima and 12 other companies. As Annex I shows, the strategy of the Japanese companies focuses with great success on standardization and cost reduction at all levels.

Also these Japanese firms often belong to large groups or large families of companies and therefore have the same advantages as their American competitors, i.e. the guarantee of a captive in-house market.

[1] It may be useful to point out that these modules are not only machines but also functional units making up machines: motor, transmission, milling and boring functions, etc.

Position of European suppliers and equipment compatibility: In Europe there do not seem to be any major overall strategies similar to those being developed by some American companies or being introduced by MITI. (This should be viewed in the light of the fact that the US and Japan are integrated economies.)

European advanced equipment manufacturers stem mainly from the traditional engineering industry and, in view of the scattered structure of this industry consisting of numerous small or medium-sized firms, it seems likely that they will be exposed to intense structural pressures forcing them to form larger units capable of meeting the new market requirements and causing many of the smallest and least adaptable firms to vanish.

The greatest asset that the European companies could have in facing up to these changes would be the existence of modular compatibility standards for different types of equipment, enabling them to specialize while remaining independent. This development would also benefit assembly firms able to purchase supplies from all sources as opposed to the large integrated companies themselves producing all the components of the system, which could be no stronger than their weakest link. In the final analysis this approach would minimize upheavals in European industry even though it would obviously not do away with adaptation difficulties (if only in respect of outlooks and attitudes) nor prevent a shake-out of firms.

To take a realistic view, there is a risk that European companies, and especially small firms in the engineering industry,[1] may give preference to a specialization strategy involving the supply of customized equipment and systems. However, this type of market slot may well become narrower and narrower with the spread of modular standardization, and the resultant modernization of production methods, offering chances of survival to only a small number of firms.

Should this hypothesis prove true the worst situation for European manufacturers would be one in which a large American or Japanese supplier succeeded in dominating the market and imposing its *de facto* standards (a situation similar to the domination of the computer market by IBM), with the following consequences:

(i) only a very few European companies would manage to continue supplying a more or less full range of equipment, probably with a reduced level of profitability and in a situation of technological dependence;

(ii) a number of European manufacturers, perhaps 15-20% of the existing industry, would succeed in gaining a foothold in one of the market slots for customized production;

(iii) a number of others would be reduced to subcontracting activities, working to specifications imposed by the dominant suppliers;

(iv) a few would try to survive by offering equipment compatible with that of one of the large suppliers, a high risk strategy;

(v) a large number would disappear.

There is a second scenario that is both more probable and less dramatic: more general norms would be imposed by the major users, meaning as things stand at present most probably the large American multinationals (and in particular General Motors). Even in this case, however, the European manufacturers as a whole would have to use norms that they had not helped to produce and that would not, therefore, give consideration to their interests or their special features. Compelled to accept outside norms, which inherently have a high technological content, the Europeans will immediately find themselves lagging behind technologically if they do not adopt a more go-ahead attitude.

In both cases the capital goods industry is unlikely to be able to keep up its contribution to the European economy and in particular its exports.

Inter-company cooperation: One factor which should act to the benefit of European manufacturers is the increasing need, as a result of the integration of different types of equipment, for a local presence to handle the installation of and after-sales service for equipment and systems. This factor and the diversity of the technologies involved account for the numerous sales cooperation and licence agreements. Here it must be recognized that European firms show a marked preference for agreements with Japanese or American firms as is shown by a recent opinion poll[2] of heads of European companies on technological cooperation:

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[1] Firms in the European electronics sector play a smaller role than their American or Japanese opposite numbers, reflecting a degree of weakness in this sector in Europe.

[2] Organized by the *Wall Street Journal/Europe* in January 1984.

(i) 27% cooperate with other companies in their country but only 21% wish to continue this;

(ii) they do not wish to cooperate more than at present with other European companies (27%);

(iii) 20% cooperate with Japanese firms but 27% would like to in the future;

(iv) 32% cooperate with US firms but 36% would like to in the future.

The reason for these trends is the underlying idea that the US and Japan have a technological lead (at least in industrial application) and perhaps also the fact that firms situated long distances away are not seen so much as rivals. Nevertheless, it does not seem up to now that the right conditions exist for cooperation at European level, which could be an important factor in strengthening European industry (in terms of specialization/volume and opening up of access to the European market).

Outlook: One potential long-term consequence of these changes should be mentioned: the capital-saving effects of this equipment make it plausible that there may be a substantial reduction in demand for advanced equipment once the integrated automation process is well in hand[1] and the acceleration of investment stemming from the renewal of obsolete machinery will have ceased. In sum there are prospects of a far-reaching and lengthy industrial adjustment in the production equipment sector.

Human resources

Obviously the improvement of productivity and radical changes in manufacturing industry will have a substantial impact on the level and structure of employment and on the organization of work.

Before these aspects are analysed, it should be pointed out that the general level of education of the workforce is of vital importance in introducing advanced equipment. Because of its very intensive industry-orientated educational system Japan has a definite advantage in this respect.

Employment level

It is difficult to evaluate the impact of advanced technologies on employment partly because technology is only one of the factors involved, and it is difficult to single it out from the general background, and partly because the various technical evaluations disagree. Estimates of job losses caused by the introduction of robots vary from 0.5 to 6 jobs per robot.

This point should be examined in detail despite the difficulties involved in such an analysis.

Although the initial evaluations of potential job losses based amongst other things on technical data from systems suppliers (see the table on the Yamazaki factory at Minokamo in Annex I) were decidedly alarming, more recent information is reassuring. According to the PSI study mentioned on several occasions in Annex I, the net job losses after the introduction of advanced equipment in British user firms[2] totalled 34 000 between 1981 and 1983, only 5% of total job losses over that period. Various case studies, in particular in Japan, confirm this type of evaluation. However, the limitations of this basically microeconomic approach covering only firms which have introduced advanced equipment should be pointed out. The framework of the analysis should be identified more clearly.

In any firm considered individually, the use of advanced equipment improves productivity, especially labour productivity, leading to job losses, but it also improves competitiveness, leading to increased market shares and boosting employment. The latter effect is likely to cause job losses to be substantially under-estimated in case studies as it may be taken that the firms introducing this equipment are amongst the most enterprising, taking manufacturing industry as a whole. It must therefore be concluded that job losses caused by advanced equipment will mainly affect companies not installing such equipment, whose market shares will dwindle as their competitiveness declines.

The lesson to be learned here is that if Europe holds back the introduction of advanced equipment in an effort to preserve jobs, its loss of competitiveness in comparison with the United States and Japan will

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[1] Even if it is postulated that the resultant improvement in productivity will lead to the creation of new industries and thence to new demand for goods and equipment or that a new flow of innovation in relation to equipment will reactivate demand.

[2] Continuous and discontinuous processes, firms with over 20 employees.

in the end destroy far more jobs than the use of advanced equipment would have done.

There is another point to be considered: up till now advanced equipment has been introduced piecemeal in Europe with a fairly low degree of integration. As gains in productivity increase substantially with the integration of advanced equipment it seems likely that the impact on employment will follow the same path. Consequently, the pace of redundancies is likely to speed up considerably in manufacturing industry when this integration process really gets going.

If manufacturing industry is considered from the macroeconomic angle, taking a medium and long-term viewpoint, potential job losses in manufacturing are probably extremely high. This is confirmed in a study by the IPA of March 1984 covering assembly (one of the most labour-intensive functions) in six of the main sections[1] of manufacturing industry in Germany. It comes to the conclusion that automation could abolish up to 250 000 assembly jobs out of the 650 000 or so covered by the study, or almost 40%.

Should it therefore be concluded that advanced equipment is a threat to employment? Nothing is less certain as the above arguments are all based on 'other things being equal' and do not take into account:

(i) Job creation as a result of the new technologies themselves, the scope of which should not be over-estimated. High technology production does not necessarily generate many direct jobs[2] or immediate profits.[3] It does, however, set the scene for future prosperity.

(ii) The displacement of a number of jobs outside the manufacturing company as some tasks, such as equipment maintenance in many cases, are no longer carried out by the company itself but are contracted to outside firms, the jobs in question thus being transferred to the services sector.

(iii) Above all the expansionist effects that productivity gains in manufacturing industry could have on production, investment and therefore job creation, not only in manufacturing itself, but in the whole of the economy.

The study which best takes into account all the facets of the problem appears to be that by Professor Leontief on the global impact of automation on employment in the US by the year 2000.[4] This extremely detailed study comes to the conclusion that automation will not cause significant unemployment, provided the necessary changes in skills and qualifications, the sectoral distribution and the geographical location of employment can be carried through successfully. Under these circumstances mobility and adaptability of the workforce will obviously play a vital role. The flexibility that exists in the US is perhaps one of the greatest competitive advantages that the Americans have over their international rivals. It is also certain that the profile of the jobs created will not be the same as that of the jobs that disappear. Although part of the process of updating skills that then becomes essential can be covered by suitable training for young people starting working life, the pace of the developments under way will make it necessary to retrain a large proportion of the existing labour force. The ability of the workers concerned to acquire the generally more advanced skills that will be needed tomorrow is a cause for concern. In this respect the higher level of education of workers in Japan is certainly an advantage. For these very different reasons the US and Japan are better placed than the Community to tackle the employment changes that will be caused by the widespread introduction of advanced equipment.

Education and training

This finding confirms the vital role of education and training in the transformation of the European economies in the years ahead.

A few figures are sufficient to demonstrate the scope of the future changes. In France the BIPE (Bureau d'informations et de prévisions économiques) estimates that about one in four jobs in French industry will be affected by the changes in skills and qualifications called for by advanced equipment over the next 10 years. It concludes that a 250% increase in further training will be required. In Germany the VDMA (the mechanical engineering federation) recently stated that the rapid

[1] Mechanical construction, electrical engineering, automobiles, metal-working, precision instruments, optical and other instruments, office machinery for information processing.
[2] Since 1965 high technology industries in the US have only created 6 million new jobs out of an industry total of 35 million.
[3] Globally the IT industry made a loss each year for 30 years and only started to become profitable at the beginning of the 1970s.
[4] See Explanatory Note 4, p. 58.

spread of CAD/CAM made it necessary to retrain about 250 000 people, 100 000 of them in the engineering industry alone.

The Commission communication of 25 January 1984 on technological change and social transformation[1] analyses in detail the problems of education and skills resulting from the introduction of new technologies and applies to a very large degree to advanced equipment.

Without repeating this analysis, it must be emphasized that both the production and the use of advanced manufacturing equipment call for a multidisciplinary approach to problems, in particular to bring about the essential merging of mechanical and electronic[2] engineering (known in Japan as 'mechatronics'), by both technicians and engineers.

As Tables 1 and 2 in Annex III show, the shortage of technicians and engineers having the necessary 'mechatronic' know-how is already apparent, especially engineers for automated production systems and technicians for their maintenance. This could in the near future create a bottleneck hampering the spread of advanced equipment, even though some efforts are now starting to be made, such as the establishment of a robotics institute at Besançon and the introduction of a course for production system engineers at Karlsruhe University. The large firms are able to train and retrain their workforce themselves, and it will be above all the small and medium-sized firms that will suffer from a shortage of personnel with the necessary qualifications.

Another aspect of the multidisciplinary approach required in the automation of industry is the disappearance of the rigid dividing line between product design engineers and production engineers, because of the ever closer links between product innovation and the design of the manufacturing process, both carried out with the help of CAD.

An example of this change is the Saturn project of GM (already mentioned earlier) where from the outset the product engineers and process engineers were brought together to develop simultaneously both the car and its manufacturing process.

In Europe and the US production engineers traditionally have an inferior role to product engineers who enjoy greater esteem. This is not true in Japan where, probably because its industrialization owed much to foreign contributions, industry considers the production engineer to be just as important as his colleague in charge of product design. This gives Japan a marked advantage at a time when industry is forced to concentrate on the production process and the process-product link.

Organization of work

To revise the design both of the production process and of the product it is necessary to adopt a fundamentally new approach to factory tasks and hence to the organization of work.

The organization of work which has now become the conventional pattern involves production line working with operations broken down into individual tasks carried out respectively by workers specializing in a specific task; flexible automation completely reverses these trends:

(i) fragmentation and specialization are replaced by multidisciplinary;

(ii) instead of specific narrowly-defined tasks carried out by an individual, there are broadly defined tasks carried out by teams (the tendency being to allocate a team of workers to a group of machines);

(iii) manual tasks are replaced by supervisory tasks which reduces physical effort but increases mental strain.

This revolution in the organization of work is accompanied by an increasing demand for flexibility on the part of workers. The more complex systems generally have to operate almost continuously and, even when they can operate unmanned for several hours, new arrangements have to be examined, especially as regards working hours (for example schedules of 4 × 10 hours a week).

One phenomenon often said to be the outcome of flexible automation is the polarization of skills with a few highly-qualified persons carrying out all the supervisory tasks and leaving to the rest of the workforce only the lowest-level jobs for which no skills are required. Most analysts agree that this is not an outcome of automation and that the structure of skills in the company depends on the policy it follows. The company has a number of choices

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[1] Bull. EC 1-1984, point 1.3.1 *et seq.*

[2] Including computer science.

open to it as regards both the type and level of automation and the organization of work around the new production system. For example, it can just as well adopt a policy of retraining existing middle management for promotion as relegate them to inferior jobs. Although there is plenty of room for manœuvre in the short term, when the company can juggle with the degree of automation of the different functions, it remains to be seen how much scope there is in the longer term.

The two sides of industry

All this shows that technological innovation must be accompanied by innovation at work, for which there must be consultation and negotiation between the two sides of industry.

Despite the direct threats to employment in manufacturing industries, it is by no means sure that the manual unions are the main source of opposition to flexible automation. According to a survey conducted by the PSI in the UK in 1983, 6% of the firms questioned considered the unions or workers to be an obstacle to the introduction of advanced equipment but 4% also saw the attitude at management level as an obstacle. The questionnaire was addressed to heads of companies.

As already mentioned in the economic analysis, the failure of European company managements to realize the importance of advanced equipment and the strategic nature of this type of investment is often a major impediment to its introduction.

As for the blue collar unions, caution must be exercised in extrapolating the above results to the Community as a whole as they reflect an attitude of principle rather than practical fact; in addition, there are slight differences in union attitudes from one country to another. Although fundamentally the French unions are in general favourably disposed to new technologies, there are more reservations in the FR of Germany, especially concerning changes in the organization of work.

One thing is clear, however: the two sides of industry must talk to each other if flexible automation is to succeed. If this dialogue is non-existent or inadequate there can be major confrontations, as Citroën and Peugeot have discovered in recent months, whereas a long-term policy of consultation can prevent mishaps like that, as Volvo's experience shows. Even though this type of comparison must be qualified to some extent because the situation and environment of the firms concerned are different, there is a valuable lesson to be learnt.

It is, of course, perfectly possible to create the conditions for fruitful discussion: advanced equipment can free workers from dangerous or disagreeable tasks, a retraining plan can lead to a higher level of training, and if planning is done sufficiently far in advance, mass redundancies can be avoided and it can be ensured that the organization of work and structure of skills will be attractive to workers and employees in the company – provided the two sides of industry view automation as an opportunity and not as a threat to employment or a way of reducing workers' influence.

Siting of companies

The fact that the jobs created will not correspond to the jobs destroyed by the introduction of advanced equipment in manufacturing industry has already been mentioned in the context of skills and qualifications.

The same is likely to be true as regards geographical location. To an increasing extent the key factor will be the availability of qualified staff and proximity to systems maintenance companies since grey matter will become an important production factor. In addition, the importance of reducing stocks and hence the advantages of 'just-in-time' delivery systems (see p. 25) give manufacturers of intermediate products for incorporation in other products an incentive to set up close to their customers, a factor that is likely to accelerate and accentuate the clustering of industry around new centres of technology.

ANNEXES

Advanced equipment and its dissemination among users

Overview

The approach adopted in this annex involves examining one by one the different types of advanced equipment, in the light of the mass of partial, dissimilar and often hardly comparable information available, in order to bring together sufficient data to paint a consistent picture of the overall situation.

The first two sections relate respectively to machine tools and robots, which constitute the basic components of the various types of automated manufacturing systems considered in the subsequent section. The scope of the study then broadens to include computer-aided design (CAD), before finally encompassing all the activities both upstream and downstream of actual production.

Each of these different subsectors is of interest *per se* and deserves to be the subject of a detailed individual study. However, it should be stressed that the whole exceeds the sum of the parts and that the real impact of advanced equipment will make itself felt above all when such equipment is integrated into automated systems.

Advanced machine tools

Definition

The term 'advanced machine tools' as used here refers to numerically controlled (NC) tools.

The first NC models, developed during the 1950s, were cumbersome and costly, while since the mid-1970s, microelectronics has brought about a number of significant developments. Thanks to DNC[1] and then CNC,[2] the mode of operation of numerical control has been streamlined considerably, by doing away with the punched card and making it possible very swiftly to amend the program controlling the machine. As a result of the increased power of microprocessors, NC can now be linked to a CAD (computer-aided design) facility, which makes it possible to introduce modifications not only to the processing sequence, but also to the product design, with a high degree of flexibility.

NC has played an extremely important role by paving the way for the development of multipurpose machines such as machining centres, which require the simultaneous control of more than two directions of movement, an achievement which was not possible before NC machines were introduced. The latest progress in microelectronics make it possible to fit machine tools with sensors for measuring torque, detecting tool breakages and recognizing parts, as well as to equip them with tool-changing systems, thus giving them a hitherto unheard-of potential for unmanned operation.

Lastly, there is an increasing trend towards fitting NC machine tools with automatic loading/unloading systems, which give an individual machine tool a capacity similar to that of a small flexible cell (composed of a machine tool and a loading/unloading robot).

Productivity and economic return

It is widely acknowledged that the changeover from a conventional to an NC[3] machine tool enables physical productivity of the machine to be increased by a factor of three chiefly as a result of the reduction in down time. Nevertheless taking into account its greater complexity (incorporation of software and electronic components) the cost of an NC machine is nearly double that of a traditional machine. As an initial estimate the return on capital employed would then be half as much again for an NC machine as for a traditional machine. However a proper evaluation of economic return should also take into account the greater wear on NC machines because of their more intensive use, the higher maintenance costs of a sophisticated machine, but also gains particularly in so far as stocks are concerned, resulting from the reduction of down time. Another aspect which should not be ignored is that the investment per machine is doubled.

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[1] DNC (direct numerical control): the machine is linked directly to a central computer (which controls one or more machines).
[2] CNC (computer numerical control): an individual microcomputer controls each machine.
[3] The term NC is used in the broad sense in order also to include more sophisticated types of control, such as CNC.

The need for sizeable investment for purchase of an NC machine can represent a significant obstacle for a small firm or for one with a weak financial structure.

Dissemination among users

The following table highlights the proportion of NC machine tools in the total machine-tool population in various countries.

	Year	*Percentage of NC machines in the total population*
United States	1983	4.7
Japan	1981	2.9
FR of Germany	1980	2.2
United Kingdom	1982	3.3
France	1980	1.6

Source: MTTA, 1984 statistics.

According to these figures, and if allowance is made for the differences between the dates on which the various surveys were conducted, no single country appears to have a taken a significant overall lead in the use of NC machines.

From a sectoral standpoint, it should be pointed out that in those countries which have an aviation industry, the latter exerts a particularly strong driving force in the demand for advanced machine tools.

Situation of European manufacturers

Traditionally, the Community machine-tool industry has been in the forefront of the international scene, with some 20% of the world market but nearly 30% of world production. Nevertheless, this position has deteriorated in recent years, and the competitiveness of the European — and in particular German[1] — industry has declined, as can be seen from Figure 1 in Annex III. This loss of ground, which is particularly heavy with respect to Japan, is closely linked with the introduction of the new information technologies.

Since the middle of the last decade, the Japanese industry has made a major investment effort aimed at standardizing its machine tools through modular design of both the machine itself and of its numerical control. This has enabled the Japanese to reduce the number of mechanical parts, while increasing the length of manufacturing series. This strategy, which, if maximum advantage is to be gained from scale and learning effects, requires a significant initial investment and the production of a large volume of machines and numerical controls, enables Japanese manufacturers, who have broadly concentrated their efforts on small machining centres and NC lathes, to arrive at unit prices well below those of their competitors. In marketing these two types of small machines, and on the basis of conventional manufacture, the Europeans have a price handicap with respect to the Japanese of between 10% and 40% on the European market and of up to 60% on the American market.[2] The result is a spectacular penetration by Japanese manufacturers of the market for small standard NC machines, facilitated by the fact that the other machine-tool producers were at the time fairly inactive in these fields, since only standardization together with volume production made it possible to arrive at prices which have created a real market.

The spectacular penetration of Japanese NC machine-tool manufacturers is illustrated by the following figures.

Production of NC machine tools

(units)

	1975	1980	1983
Japan	2 182	22 052	26 398
USA	4 136	8 856	8 000
FR of Germany	1 085	4 743	8 000
UK	739	1 240	1 800
Italy	800	2 700	3 000
France	500	1 100	1 300

Sources: Jetro, IPA, Cecimo.

The lower rate of increase between 1980 and 1982/83 is to be associated with the drop of some 20% in total machine-tool production during the same period.

It should be stressed that machining centres and NC lathes — nearly all of small capacity — account for nearly 70% of Japan's total NC machine-tool

[1] The Federal Republic of Germany accounts for more than half of Community production.
[2] Analysis of production costs forming part of the strategic study of the Community machine-tool industry, which is in preparation.

production and that as far as the other types of machine tool are concerned, the European industry generally retains a strong position. Thus, to take the example of reaming machines, only 6-7% of Japanese production is equipped with numerical control, whereas the corresponding figure for the Federal Republic of Germany is nearly 50%. Furthermore, Japanese penetration of the European market in NC lathes and machining centres has slowed down considerably over the last two or three years, thanks to the restraint imposed by MITI in the form of minimum prices for exports of machine-tools,[1] which are thought to have had the effect of increasing the prices of Japanese machine tools sold in Europe by between 30% and 40%.

Nevertheless, while action of this nature makes it possible to paper over some of the cracks, genuine and lasting solutions can only come from the European side. Despite encouraging signs[2] that European manufacturers are making an effort in order to face up to the challenge of the new information technologies, their underlying situation remains vulnerable, since they have not yet reached the volumes nor introduced the automated production methods which would enable them to compete in economic terms with Japanese manufacturers of machining centres and NC lathes at the lower end of the market.[3]

European manufacturers can continue producing this type of machine only with the aid of the cash-flow generated by the remainder of their activities. Furthermore, increasing possibilities are emerging for applying these production techniques to other types of machine, in particular machining centres and medium-range NC lathes: this is liable in future to expose European manufacturers to fiercer competition in these sectors also.

From the automation standpoint, it is also necessary to stress the increasing importance of machining centres, since they constitute one of the basic components of flexible manufacturing cells and systems.

The outlook for demand

The machine tools market underwent the worst recession of the postwar period between 1980 and 1983, and the majority of experts expect to see a marked recovery in the years ahead. The American analysts Frost and Sullivan make the following forecasts for the overall demand for metal-removing machine tools (in USD million): 1980: 5 642; 1983: 3 900; 1985: 4 650; 1987: 5 870; 1990: 7 440.

Within overall demand, the share of NC machines has been steadily increasing in recent years. An indication of that fact is given by the increasing share of NC machines in total machine-tool production: between 1980 and 1982, that proportion (in value terms) rose from 17% to 27% in the Federal Republic of Germany; from 15% to 23% in the United Kingdom; from 29% to 35% in the United States;[4] from 50% to 54% in Japan.

In more concrete terms, the London based Policy Studies Institute conducted a survey in 1983 of the intentions of a representative sample of British industry. According to the results of that survey, the population of CNC machine-tools in the United Kingdom[5] increase from 17 000 units in 1983 to 27 000 units in 1985, which represents an annual growth rate of some 25%, a figure that does not conflict with the other indications in the Commission's possession.[6]

It can therefore be expected that the population of advanced machine tools will continue to increase sharply in the years ahead, as they replace less sophisticated conventional machines. Nevertheless, in the longer term, this period of rapid growth could possibly be followed by an appreciable decline, as a result of the combined effect of several factors:

(i) the slowing-down of the process whereby conventional machines are replaced by NC machines;

(ii) the greater productivity of NC machines in comparison with traditional machines, which makes it possible to reduce the investment and the number of machines installed for an identical volume of production (this factor being partly offset by the fact that machines are used more intensively and therefore have to be renewed more quickly);

[1] These prices have been applied to exports to the United States and Canada since 1978 and to the EEC since 1981.
[2] See Explanatory Note 5, p. 58.
[3] Annual production of these types of machine amounts to between 150 and 375 machines in Europe, as against some 1 500 machines in Japan.
[4] Machines costing more than USD 2 500.
[5] In firms employing a workforce of more than 20.
[6] See Explanatory Note 6, p. 58.

(iii) the increasing integration of NC machines into automated systems in which, for an identical production capacity, the number of machines required can be reduced to one-third of conventional needs and whose impact, for a constant level of investment, can, according to the Boston Consulting Group, be evaluated as follows:

Proportion of NC machines sold as part of a system 5% 10% 25% 50%

Reduction in the demand for NC machines – 5% – 9% – 20% – 33%

(iv) the decline in the need for machining as a result of better product and component design;

(v) the emergence of metal substitute materials and new manufacturing processes.

Industrial robots

Definition

The term 'robotics' is often used very loosely to cover the entire process of manufacturing automation. The intention in this section is, however, to deal specifically with industrial robots, which can be defined in several ways, i.e. either from an overall standpoint, or according to their specific characteristics (degree of sophistication), or according to functional categories. In contrast with what could be expected, the definition of robots is far from being a purely academic question: a few years ago, the JIRA[1] proposed a very broad five-category definition of robots, which was adopted in 1979 as a Japanese industrial standard (JIS). According to this definition, there were a total of 76 500 robots installed in Japan in 1980, as against 4 500 in the United States and 4 000 in western Europe. On the basis of the European and American definitions, the figure for Japan would in fact be closer to 5 500 units. It can, however, be imagined that the psychological impact of announcing such a lead in Japan has been considerable. Adopting such a broad definition also made it possible to include among Japanese producers of robotic equipment a large number of manufacturers of fixed manipulators, who thus received considerable support from MITI, the effect of which was to stimulate them to develop more sophisticated equipment, and thus to venture into markets they would probably otherwise not have tackled.

In the following analysis, the use of the term 'robot' will correspond to the definitions adopted by the ISO, the Robot Institute of America and the British Robot Association,[2] which are fairly similar and from which it emerges that robots display the following features:

(i) they handle parts, tools and specialized implements;

(ii) they are reprogrammable;

(iii) they are multifunctional;

(iv) the programming of their motions is variable.

This nevertheless covers a large range of robots, from the simple playback robot, which stores in its memory a sequence of actions demonstrated by the operator, to the intelligent robot, which is capable – by virtue of its sensorial capacities – of reacting to the working environment.

Productivity and economic return

Given the diversity of robots and the fact that they were introduced into manufacturing processes only recently, it is difficult to quantify the productivity or efficiency of robots in general.

A yardstick with which to gauge the productivity of a robot can, however, be given by the time it takes to pay back capital invested. Operating on the basis of two shifts a day, the initial investment can currently be recovered, in favourable cases, within about two-and-a-half to three years for handling/transfer robots, welding robots and paint-spraying robots. In the last analysis, however, it should be stressed that the productivity of the robot must be considered in terms of its contribution to a partly or fully automated production system, in which the robot plays a vital role in providing flexibility by virtue of its versatility and its ability to be reprogrammed. Again, idle time is reduced considerably, in particular during machine-tool loading/unloading operations, as a result of the elimination of the safety precautions necessary for human operators.

[1] Japan Industrial Robots Association, a manufacturers' federation founded at MITI's instigation.
[2] See Explanatory Note 7, p. 59.

Estimated robot population in various countries

Country	'78	'80	'81	'82	'83	*Average annual growth, 1980-83*
FR of Germany	450	1 200	2 300	3 500	4 800	41%
UK	125	371	731	1 152	1 753	47%
France	n.a.	580	790	1 385	2 010	36%
Italy	n.a.	400	450	790	1 800	46%
Total	n.a.	2 551	4 253	6 827	10 363	42%
Japan	3 000	6 000	9 500	13 000	16 500	29%
USA	2 500	3 500	4 500	6 250	8 000	23%
Sweden	800	1 133	1 700	1 300[1]	1 900[1]	n.a.

[1] Figures revised downwards after a definitional modification.
[2] The OECD has gathered its data from different sources (the BRA, the BIPE, Diebold and the STT), so they are not necessarily entirely comparable.

Source: OECD[2], British Robot Association and Association Française de Robotique Industrielle.

This comparison clearly demonstrates that, after a relatively slow start, the dissemination of robots in European industry has continued at a faster pace, enabling the Community to make up part of the ground lost to Japan and even to overtake the United States in 1982-83. Nevertheless, in order to make the comparison more realistic, these absolute figures concerning the robot population should be related to employment in industry.

Number of robots per 10 000 workers in industry (NACE2/4)

Country	*1978*	*1980*	*1983*[1]
FR of Germany	0.5	1.4	6.3
UK	0.2	0.6	3.4
France	n.a.	1.1	4.1
Italy	n.a.	0.7	3.4
Japan	2.3	4.4	11.8
USA	1.1	1.6	3.9
Sweden	7.8	11.0	20.3[2]

[1] Commission estimate for employment in 1983.
[2] Not comparable with previous figures (see preceding table).

The lead taken by Sweden and, to a lesser extent, by Japan, in the use of robots therefore remains significant. Taken as a whole, this table confirms that the Community has caught up with the United States, and the particulrly rapid dissemination of robots in the Federal Republic of Germany since the beginning of the 1980s is worthy of special mention.

It is also of interest to examine the dissemination of robots sector by sector.

Distribution of robots according to user industry

This table (p. 35) shows the major role played by the transport industry, and in particular the motor industry, in the Federal Republic of Germany and the United Kingdom. The same applies in France, where 958 out of a total robot population of 2 010 in 1983 were installed in the motor-manufacturing industry; the proportions were probably similar in Italy. It is interesting in this context to set out an international comparison of the use of robots in the motor industry, classified in decreasing order of utilization rate. The first four places in this classification are occupied by Community firms (it would, however, have been ineresting to include Volvo), three of which are German, which helps explain the rapid growth of the robot population in the Federal Republic of Germany.

Situation of European manufacturers

In the early stages of the development of industrial robots, the world robot market was dominated above all by independent American manufacturers. In first place among the latter came the firm Unimation — subsequently absorbed by Westinghouse — which in 1982 still held 32% of the

Distribution of robots according to user industry

(%)

	Germany (1981)	UK (1980)	Japan (1980)	Sweden (1979)
Transport, including	46	39	n.a.	22
(i) motor vehicles	n.a.	34	30	n.a.
(ii) other	n.a.	5	n.a.	n.a.
Electrical	14	5	36	9
Mechanical	12	10	n.a.	15
Metal products	6	17	5	51
Injection moulding of plastics	6[1]	14[2]	10	n.a.
Other	16	15	19	3
Total	100%	100%	100%	100%

[1] Plastics and other materials.
[2] Plastics and rubber.

Source: OECD, Commission presentation.

Manufacturers	*Number of vehicles produced (1982)*	*Number of robots (1982)*	*Number of robots per 100 000 vehicles*
Mercedes (D)	480 000	550	114
BMW (D)	360 000	350	97
Volkswagen-Audi (D)	1 538 000	950	62
Fiat (I)	1 186 000	640	54
GM (USA)	4 630 000	2 300	50
Toyota (J)	3 145 000	1 400	44
Nissan (J)	2 408 000	1 000	41
Mazda (J)	1 110 000	430	39
Chrysler (USA)	967 000	360	37
Ford Europe	1 233 000	400	32
Renault (F)	1 719 000	450	26
Peugeot SA (F)	1 423 000	350	25
Ford (USA)	2 192 000	500	23

Source: Peugeot SA.

American market, nearly 25% of the European market and approximately 15% of the world market in robots.

Nevertheless, the situation has changed since the middle of the last decade: Japanese production has developed rapidly under the impetus of coordinated action by MITI aimed at developing both the production of and the demand for robots in Japan (see p. 23). The results have been spectacular and can be illustrated by the following comparison:

Production of programmable robots in 1982

Japan	7 000
Europe	3 200
USA	1 800

Source: Frost & Sullivan.

In Europe, independent Scandinavian manufacturers such as ASEA and Trallfa, which have just concluded an important cooperation agreement (also including their Japanese and American partners) have been at the forefront of the world scene for several years, as can be seen from the following table:

Percentage share of the Western European market in 1981

Unimation (USA)	23
Trallfa (Norway)	20
ASEA (Sweden)	15
Electrolux[1] (Sweden)	5
Volkswagen (FRG)	12
Kaufeldt (Sweden)	4
Others	21

[1] The interests of Electrolux in the robot field have since been taken over by ASEA.

Source: OECD.

The substantial market shares held by the Scandinavian manufacturers partly reflect the extremely high utilization rates in those countries, and particularly in Sweden. Since 1981, European producers have grown, notably in spot welding (Kuka in Germany, ACMA in France, Comau in Italy) with a strong showing by ASEA and a weakening of Unimation.

In spite of the foregoing, all the signs indicate that robot production in the Community has developed appreciably since that date, and this development can largely be associated with the more rapid introduction of robots in the European motor industry. Community motor manufacturers are themselves largely responsible for the manufacture of these robots (which are intended for captive markets). The firms ACMA (a Renault subsidiary), Comau (a Fiat subsidiary) and Volkswagen can be mentioned in this connection. Given the dominant role of the motor industry in the demand for robots and the rapidity with which the Community industry is introducing them, this process should boost production within the EEC considerably.

From a different standpoint, a remarkable example is provided by Italy, where robot production, which represented only 30% of domestic demand in 1975, rose to nearly 140% in 1979. Italian manufacturers succeeded in taking full advantage of a rapidly-changing market on which there are a large number of highly-specialized applications.[1] Such applications lend themselves well to individualized production, to which the structure of Italian industry is geared very effectively. At the other end of the scale, in the United Kingdom, the proportion of demand covered by domestic production increased from 23% in 1980 to 34% in 1983. It should not, however, be forgotten that these figures also incorporate American or Japanese robots manufactured under licence in Europe. Although the overall position of Community manufacturers is weak, the emergence of a series of European manufacturers and European know-how in the area of assembly – DEA and Olivetti in Italy, Bosch and Mantec (Siemens) in Germany, Scemi (CGE) in France – makes it possible to face the future with some optimism.

Although economies of scale have so far not played an important role for European manufacturers, it should nevertheless be pointed out that the Japanese industry, adopting here the same approach as for NC machine tools, is pursuing a strategy aimed at lowering costs through series production based on modular standardization. Instead of attempting to construct highly sophisticated – and therefore costly – robots that can carry out a large number of number of functions, the Japanese industry is concentrating its efforts on the development of modular structures and simple, fast and inexpensive robots (of the Scara type), each of which is capable of performing only a limited number of tasks, but can be combined in order to obtain the desired result. At the present time, Japanese robot exports remain scarce, since Japanese manufacturers appear to prefer trade agreements and, to a lesser extent licensing agreements, which involve less risk in a market that is still relatively limited and on which local presence (for maintenance purposes) is highly important. Unless this situation is the result of a deliberate policy aimed at avoiding frictions in trade, there is still a genuine likelihood that competition from outside the Community will become much fiercer in the years ahead.

As far as licensing is concerned, although many agreements have been concluded between European firms, on the one hand, and American and Japanese firms, on the other hand, one cannot fail to be struck by the virtual nonexistence of intra-European agreements. In the last analysis, it should be borne in mind that of all types of advanced equipment, robots have attained the lowest level of maturity, and that this is therefore a highly volatile and rapidly expanding market on which no position should be taken for granted.[2]

[1] Listed in Explanatory Note 7, p. 59-60.
[2] See Explanatory Note 9, p. 60.

The outlook for demand

From a quantitative standpoint, the OECD has compiled in its 1983 study a whole set of forecasts from different sources of the growth of the robot market in a number of OECD countries. These forecasts are set out in Table 3 in Annex III.

In general, forecasts for the total annual growth of this market range between some 25% and 30%, which does not appear unrealistic in view of previous growth rates.

The current world robot market is estimated at approximately USD 500 million.[1] In the light of data compiled by the OECD, the size of the market could attain the following figures by 1990:

(i) between USD 1 500 million and USD 2 000 million in the United States;

(ii) nearly USD 1 000 million in Europe;

(iii) approximately USD 700 million in Japan.

From a qualitative standpoint, a sizeable increase can be expected in the use of robots for assembly work, as witnessed by the following forecasts:

Robot functions

	1981	1990
Spot welding	40%	3%
Handling/loading and unloading of machines	29%	32%
Surface treatment	11%	4%
Assembly	6%	35%
Arc welding	6%	16%
Other	8%	10%
	100%	100%

Source: Arthur D. Little.

These changes must be interpreted in the light of the considerable growth of the market which is expected between now and 1990. As far as the user sectors are concerned, the motor industry will probably remain one of the largest robot users. It is to be expected that the use of assembly robots in the microelectronics sector will develop swiftly and that, in general, the use of robots will progressively take hold in most branches of industry.

The growing importance of assembly should, furthermore, be beneficial for European manufacturers, who possess international know-how in this field (robots and assembly gantries).

Flexible manufacturing cells, systems and transfer lines

Definitions

Definitions play an important role here, as elsewhere, and the differences between them go a long way towards explaining the discrepancies – and even contradictions – that appear in the various studies on flexible systems.

In the rest of this paper we propose to use the following definitions.

Flexible manufacturing cells are composed of a number of machine tools (often standard machines) which are interlinked but work in a fixed sequence according to an operational programme. In its simplest expression, a flexible manufacturing cell (FMC) will consist of a machine tool coupled with a robot, but it can also comprise a number of machine tools (normally less than five) with or without a robot. Such cells will normally process series of between 20 and 500 workpieces.

Flexible manufacturing systems (FMS) are also composed of several machines, like the cell, but possess a software capacity that enables the routing of workpieces to be variable and optimized. The FMS requires a business computer, part-recognition algorithms, loading times, etc. The software is much more sophisticated than that of a flexible manufacturing cell, since the FMS has 10 times more computing power. Variable routing of workpieces presupposes the need for a sophisticated transport system, which is often composed of self-guided vehicles. Series normally consist of between 50 and 2 000 workpieces.

Flexible transfer lines: as in the case of conventional transfer lines, the work proceeds along a rigid line and according to a fixed sequence with specific machines for each operation, but the different stations become numerically controlled and possibly linked to a central computer. This is what gives the line its flexibility, making it possible to modify

[1] According to a *Financial Times* survey dated January 1984.

the positioning or size of the workpieces very swiftly. In comparison with a conventional line, on which a single workpiece is machined, the flexible line makes it possible to process a small family of workpieces, but the length of series remains large: between 1 000 and 10 000 workpieces.

By putting these definitions alongside those of advanced machine tools and robots, it becomes possible to define the entire range of current machining possibilities, in terms of productivity and flexibility, as illustrated by Figure 2 in Annex III. This shows how advanced equipment makes it possible to combine productivity and flexibility in order to arrive at the partly or fully automated manufacture of small series, which becomes feasible for the first time. Another feature of this type of flexible system, and above all of the FMS, is its capacity to operate unattended, sometimes for about 10 hours. The latter aspect is extremely important in the case of equipment that often has to be operated continuously, 24 hours a day.

The preceding three definitions have been presented in increasing order of the size of machining series, but not in increasing order of systems complexity and therefore cost. It should be noted that the FMS, with its highly sophisticated software, offers the greatest degree of complexity and flexibility in terms of the rapidity with which it can adapt to the market. It is at this level that definitions take on not only theoretical, but also practical importance: the Americans include flexible transfer lines in the FMS category, whereas the Japanese tend to group together the three types of system under the heading FMS, thereby systematically giving a broader interpretation. Even in Europe, experts often tend to regard the larger flexible manufacturing cells (i.e. those comprising a larger number of machines) as flexible manufacturing systems, even if they do not fulfil what is in our view the decisive criterion, namely that the routing of workpieces must be optimized and variable.

Productivity and economic return

The situations vary according to the type of system concerned.

Flexible manufacturing cells

Flexible manufacturing cells have now attained a high degree of profitability and make it possible to reduce unit costs appreciably, possibly by some 25%. The main reason for this saving is the reduction in labour costs. It is again worth noting that a sizeable initial investment is necessary.

FMS

The analysis has to be much more subtle. Technical calculations often quote spectacular results, as illustrated in the following comparison:

Comparison of the Yamazaki Factory at Minokamo (four interconnected flexible manufacturing systems) with a traditional plant of the same capacity

	Minokamo	Conventional plant
Number of machine tools	43	90
Workforce	39	195
including: workers	36	170
supervisory staff	3	25
Manufacturing time	30	91
Surface area (m^2)	6 600	16 500

Source: VDI – Z (January 1984).

The economic facts nevertheless urge one to make a much more cautious assessment, since the size of the investment – which increases more than in linear proportion to the complexity of the system – is such that the economic return is generally acceptable only if the system operates without any problems – and therefore without too many stoppages – and does not lead to additional external costs (e.g. redundancy payments). There are often still technical problems, which increase exponentially with the complexity of the system, concerning workpiece handling, tool control, machine reliability and software. Furthermore, a fall in the demand for the finished product suffices for it to be necessary to continue operating the system on the basis of only two shifts instead of three (16 hours instead of 24 hours a day), thereby considerably reducing its profitability. It emerges from these facts that in the absence of tax incentives or other government measures, the profitability of FMS is still fairly marginal in the majority of cases.

There is, however, one exception to this rule, namely that to the industries in which there is a wide variety of workpieces to be machined, which have a high unit value and for which the production sequence cannot be foreseen with certainty. In these cases, of which the aviation or machine-construction industries are good examples, the only way of holding down delivery time hitherto consisted in keeping large stocks. FMS makes it possible precisely to eliminate – or at least considerably reduce – the amounts of stocks and work in progress and is thus fully justified from an economic standpoint, since the return on investment is multiplied by a factor of four or five in comparison with other cases. If an FMS is to attain maximum efficiency, it must therefore often be associated with an automatic handling and storage system. The latter may be composed either of a central store in which, under the control of the central computer, self-guided trucks fetch the components required from the different parts of the store, or from a series of smaller stores. In addition to the advantages associated with FMS, automatic stock-keeping brings about major savings in terms of accuracy, stock control, the floor area required, security and the reduction in the number of rejects.

To conclude, it should again be stressed that all benefits of FMS do not necessarily lend themselves to conventional financial analysis, since account should be taken of aspects such as the competitive edge gained as a result of the reduction in delivery times, the reduction in the number of human errors and therefore the improvement in the quality (and in particular the manufacturing tolerances) of the finished product.

Flexible transfer lines

In comparison with conventional transfer lines, which are already widely disseminated, the design of flexible lines is much more modular, since control is exercised at each work station rather than centrally. Modular design makes for greater standardization of the control components and, to a lesser extent, of the mechanical components and therefore reduces the cost of a transfer line by up to 25%. To this are added the benefits deriving from the greater versatility of this equipment, which have already been mentioned.

Dissemination among users

The confusion surrounding definitions makes it difficult to interpret statistics relating to flexible systems, particularly when comparing different countries. The following table, which traces the evolution in the number of FMS systems in Europe, Japan and the United States, is therefore presented with major reservations. The figures, drawn from a study in progress on behalf of the Commission, have been taken from various sources. Moreover, they are based on a definition of FMS which also encompasses the larger flexible cells.

Year	Europe	US	Japan
1967		1	
1969		2	
1970		4	
1971	1[1]		
1972		5	4
1973		6	
1974	2[2]		6
1975			20
1976	6[4]	7	24
1977	7[5]		26
1978	9	8	
1979	15[9]	14	
1980	17	17	28
1981	21[11]	21	35
1982	31[17]	27[1]	45
1983	41	34[1]	

[1-17] FRG.
[1] Figures incomplete.

This evolution could be broadly broken down into three phases:

(i) the initial lead taken by the Americans at the beginning of the 1970s;

(ii) the spectacular breakthrough by the Japanese from 1975 onwards;

(iii) the intense effort made by the Europeans since the beginning of the 1980s with a view to making up lost ground.

Given the importance of government incentives in determining whether FMS is profitable, the Japanese breakthrough and, more recently, the accelerated pace of development in Europe are associated with the major stimulation policies implemented by governments, which are analysed in Annex II. There are no comparable figures for flexible cells and transfer lines. Mention is often made of a figure of 100 or even 200 flexible manufacturing systems in Japan, according to the scope of the definitions assigned thereto.

As far as transfer lines are concerned, a trend is currently under way towards the rapid, large-scale replacement of traditional lines by flexible lines. In Europe in 1982, only 10% of lines were flexible, whereas half of all new orders in 1984 were for flexible ones.

Transfer lines are used above all in the motor industry. The Commission does not possess any statistics on the sectoral distribution of flexible cells. As far as FMS is concerned, the following table gives an insight into the distribution of flexible manufacturing systems among the various branches of industry, on the basis of an international sample.

	Japan	US	FR Germany
Motor industry (including components)	3	2	5
Agricultural and construction machinery	4	8	1
Construction of machines	15	1	4
Heavy engineering	4	—	—
Precision engineering	—	1	1
Electricity and electronics	2	1	2
Aviation	--	4	2
	28	17	15

Source: Boston Consulting Group.

Situation of European manufacturers

Given the importance of maintenance and after-sales service in the case of complex systems and the length of start-up periods (often nearly two years) in the case of FMS, local presence proves indispensable for the sale of systems. This explains why the vast majority of the systems in existence in Europe have been installed by European firms. German and Italian manufacturers have taken the lion's share of this market. Italy's good performance is worthy of special mention, since despite a very weak domestic base (there are reported to be only four or five flexible manufacturing systems installed in Italy), there are several major manufacturers (Comau, Olivetti, Berardi, Mandelli and SAIMP), who have been highly successful on the European market.

While a statement of the number of flexible manufacturing systems installed (see the preceding two tables) gives an initial insight into the relative position of manufacturers in the different regions of the world, account should also be taken of qualitative criteria: the number of different parts produced, the size of the system, the degree of integration and potential for unmanned operation.

	Number of systems			
	5-10	11-100	101-200	over 200
	Number of parts produced			
USA	12	2	1	—
Japan	6	8	3	2
FR of Germany	2	3	11	2

Source: Boston Consulting Group.

This comparison should be approached with caution, since it possibly also reflects differences in definition. It nevertheless highlights the strong position of the German industry as regards the flexibility[1] provided by the capacity to machine a wide variety of different workpieces (which is a gauge of the complexity of the software).

As far as the size of systems and their degree of integration is concerned, Japan appears to have taken the lead and possesses four extremely large systems comprising more than 15 machines (in particular Fujitsu Fanuc, Mori Seiki and Yamazaki), as compared with two such systems in Europe and one in the United States. Subject to the same reservations concerning definitions, we have compiled data from different sources[2] in order to arrive at the following sample:

Number of machines	Number of FMS		
	United States	Japan	EEC[1]
5	2	12	6
6-10	10	7	7
11-15	4	1	3
16-20	—	1	1
20	1	3	1

[1] Federal Republic of Germany, France and United Kingdom.

Furthermore, the different sources concur regarding the higher degree of integration of Japanese installations, which is reflected in their large potential for unmanned operation: there are reported to be 15 flexible manufacturing systems in Japan that are capable of operating unattended for approximately 10 hours, as against only two such systems in Europe.[3]

As regards less complex systems, i.e. flexible manufacturing cells, international competition appears to be on the point of becoming keener, since Japanese manufacturers, adopting their usual strategy, have developed standardized cells which they are preparing to export and which have already obtained a measure of success in the US. Unless they react speedily European and US manufacturers of 'tailor-made' cells risk being overtaken as they have been with machining centres and NC lathes.

Outlook for demand

This varies appreciably depending on the type of equipment under consideration.

Flexible cells are of proven profitability and represent an investment in principle financially within the means of medium sized firms (over 500 employees). There are practical problems (as emerges from the financial analysis on pages 21to 23) but the scope for expansion is nevertheless considerable.

In the case of *flexible transfer lines* a process of substitution for conventional lines is involved. In this respect the speed of this process has already been noted. It is forecast that in 1995 no more than 10% of demand will be for conventional lines, while the remainder will be for flexible lines and to a more limited, but nevertheless, unpredictable extent, by flexible cells and FMS.

The scale of the investment necessary in order to install flexible manufacturing systems means that only large firms can do so (9 flexible manufacturing systems out of 10 are set up by firms with a workforce of more than 2 000): this therefore considerably limits the potential market. Since a large proportion of the savings made by FMS are associated with the reduction in idle time, which is proportionally shorter in the case of large workpieces, FMS is chiefly suitable for small workpieces, and this further reduces the potential for expansion.

Nevertheless, under the impetus of measures taken by governments, it can be expected that the rapid growth in the number of flexible manufacturing systems in service will continue, as can be seen from the following figures, which are of value above all as a guide.

Flexible production systems[1] in Europe

	Operational	Planned	Total
Belgium	4	—	4
France	3	15	18
FR of Germany	5	26	31
UK	4	21	25

[1] Definition which could include flexible manufacturing cells.

Source: NEDO, 1984.

[1] In the context of FMS the concept of flexibility has two aspects — number of parts machined and flexibility of stocks (inventory flexibility) which is considered above.
[2] NEDO Advance Manufacturing Systems; Yoshikawa, Rathmill and Havatny: Computer Aided Manufacturing; VDI-Z; A. D. Little; ISI; study under way for the Commission.
[3] Study on FMS under way for the Commission.

Computer-aided design (CAD)

Definition

CAD covers a wide range of applications, throughout the whole of industry, based on computerized graphic systems and associated with product and process design activities.

At product level, CAD ranges from simple units making it possible to produce two-dimensional drawings or plans to systems equipped with complex three-dimensional modelling software. Analyses and definitions are often confined to this aspect of CAD, which, however, encompasses much more than the functions mentioned. Still at product level, CAD may be associated with CAE (computer-aided engineering) i.e. software making it possible to analyse the design and assess the performance of parts (e.g. deformation under heat, shear strength, etc.). In certain cases, CAE can make it possible to dispense with costly prototypes. There are also major applications of CAD at process level, in the planning of the use of machines and of their operating sequence, chiefly in what is termed the 'group technologies'. The principle underlying the latter is simple: the idea is to exploit the opportunities offered by CAD[1] in order, on the one hand, to identify and collect together the parts to be manufactured, not on the basis of the product for which they are intended, but according to their inherent similarities, and on the other hand, to classify the different processes so that they can be organized into cells, each assigned to the manufacture of a set of parts belonging to one and the same family, as defined with the aid of CAD. CAD can also be used in order to establish the manufacturing programmes for NC machine tools.

Productivity and economic return

The benefits of CAD are difficult to quantify. Clearly, CAD brings about an often spectacular reduction in the lead times for designing and developing a product, with a corresponding shortening of the latter's life cycle. Nevertheless, the savings made are also due to the lowering of production costs, not only as a result of process planning and group technologies, but also through the optimization of product design and use of materials. The 1977 Peugeot 305 thus comprised 3 700 spot welds, whereas this figure was reduced to 2 500 in the Peugeot 205 launched in 1983. To this should be added the improvement in quality that is achieved as a result of better design, as well as the increased flexibility afforded by CAD. Lastly, it should be stressed that a whole set of products, ranging from advanced microelectronics components to the latest generation of aircraft, could not have been produced at all, were it not for CAD.

On the basis of an enquiry into American users Fine Control Data has presented a series of coefficients of productivity for CAD:[2]

Productivity coefficients
(average statistical value)

Electronics applications	
Establishment of logic circuits	3.0- 5.0
Wiring diagrams	3.5- 4.5
Design of printed cards	3.5- 4.5
Integrated circuits	10.0-20.0
Mechanical design	
Detailed design	2.0- 3.0
Establishment of drawings	2.0- 4.0
Designs	2.5- 3.5
Production of sheet metal	3.5
Piping design	2.5- 3.5
Tender documents	3.0- 5.0
Production of NC punched tape	4.0- 6.0
Other sectors	
Layout planning	3.0- 4.0
Data processing, calculation and utilization	3.0- 6.0

These productivity coefficients tally with indications obtained from other sources.[3] Nevertheless, in terms of economic return, such technical calculations should perhaps be moderated, since the high cost of CAD systems apparently often results in amortization periods being fairly long (Boeing reckons that it will recoup its investment in CAD equipment over a period of seven years), while standard software packages often appear ill-adapted to the needs of firms unable to develop their own software. In reality, the benefits for the firm will depend heavily on the latter's individual situation

[1] By creating data banks providing a highly detailed geometrical description of parts and allowing for classification of parts and also of processes used in their manufacture.
[2] At a seminar organized by the German mechanical engineering industry in September 1983.
[3] See Explanatory Note 8, p. 59.

and on the number of operations to be carried out on CAD equipment. CAD can thus be highly profitable for a small design office with a few employees, whereas it would not be justified for a large firm with only limited CAD work to be carried out. Furthermore, these benefits are to a great extent difficult to quantify.

Lastly, account should be taken of the rapid technological progress in this sector, which is leading to a constant reduction in the cost of hardware and software, the marketing of an ever-increasing range of standard software packages and the emergence of companies offering specialized CAD services to small users who are unable to acquire their own equipment.

Dissemination among users

The world CAD market, which amounted to USD 1 600 million in 1983, has grown at a rate of 30% a year over the last two years, and should again increase by 45-50% in 1984 in order to reach the figure of USD 2 300 million.[1] Nevertheless, CAD is still employed on a very small scale in Europe in comparison with the United States and Japan.

By way of comparison, the German mechanical engineering industry association (VDMA) estimates that some 50% of Japanese firms in the mechanical engineering sector are currently using CAD. The corresponding figure for the Federal Republic of Germany is approximately 3%. Another more general indication is given by the following table.

Estimated levels of CAD utilization (1982)

	Number of CAD systems	*CAD systems as a % of GDP*
Norway	70	1.6
Sweden	208	2.4
France	562	1.2
FR of Germany	375	0.6
UK	620	1.6
USA	6 600	3.5

Note: The author states the need for caution concerning the validity and comparability of these figures.

Source: Arnold-CADCAM International, August 1984.

Unquestionably, therefore, European firms are lagging far behind the United States and Japan in the use of CAD. The lead taken by the latter countries is all the greater when it is borne in mind that a period of between several months and two years is necessary in order to learn how to use CAD and reap all its benefits.

Situation of European manufacturers

The world CAD market is dominated far and away by the major American manufacturers:

Shares of the world CAD market

	1983 (USD million)	*Market share*[1] (%)
Computervision	403.0	23.3
IBM	332.0	19.2
Intergraph	255.0	14.7
GE-Calma	159.0	9.2
Schlumberger-Applicon	103.0	6.0
McDonnell Douglas Auto	70.0	4.0
Auto-Trol	53.0	3.1
Control Data	49.2	2.8

[1] Market estimated by Daratech Inc. at USD 1 700 million in 1983.

Source: Daratech Inc.

As far as the European market is concerned, American manufacturers hold approximately a two-thirds share, as can be seen from the following figures (p. 44).

These figures reveal that German manufacturers are lagging seriously behind, a fact which is also reflected in the low level of penetration of CAD in the Federal Republic. The situation in France and the United Kingdom is slightly more encouraging, although generally speaking, it is particularly striking to note the extent to which European manufacturers concentrate on their domestic markets.

The strength of American manufacturers and the high level of penetration of CAD in the United States can be ascribed to the pull exerted by military research and the support given in the form of the large market provided by the aerospace industry (both a leading-edge and a volume market). There is, however, considerable know-how in Europe, especially in the software field. The European

[1] *Source*: Merril Lynch.

Shares of the European CAD market held by various suppliers

(%)

Supplier	*France (1982)*	*FR of Germany (1981)*	*United Kingdom (1981)*
Applicon (US)	21	10	3
Computervision (US)	36	32	29
IBM (US)	n.a.	n.a.	12
Others US	5	18	20
Secma (F)	12		
Matra (F)	6		
Siemens (D)		8	
Racal (UK)	11	7	15
Compeda (UK)			6
Ferranti (UK)			2
Quest (UK)			10
CIS[1]			2
Share of local manufacturers	23	11	36
Share of European manufacturers	38	40	36
Share of American manufacturers	62	60	64

[1] Since taken over by Computervision.

Note: Caution required regarding the validity and comparability of the figures.

Source: Arnold-CADCAM International, August 1984.

aviation industry, and in particular the Airbus programme, is acting as a catalyst in this area. Certain European firms are highly successful in specialized outlets, to such an extent that big American firms use them (as in the case of IBM, which markets the Catia system developed by Dassault) or buy them out (e.g. CIS in the United Kingdom, which was taken over by Computervision).

Another important factor to be borne in mind is that in many instances, the most highly sophisticated CAD systems are developed for internal use. This is the case, in particular, not only of IBM and other large American firms, but also of certain major Japanese industrial groups. Where such systems are eventually placed on the market, it is with considerable delay, since the firms concerned are more anxious to take advantage of the overall competitive edge they derive from using such CAD systems than to market them.

The outlook for demand

As far as the other types of advanced equipment are concerned, pundits generally expect there to be a high level of market growth.[1] As regards the Community, the only concrete indication we had related to the United Kingdom market: the number of CAD terminals in industry should increase from 9 000 in 1983 to 14 000 in 1985, which represents an annual growth rate of some 25%.

Industrial computing and other types of advanced equipment

The term 'industrial computing' is used here fairly loosely in order to refer to a range of computerized industrial management tools.

Upstream of manufacturing, computer-aided design — which, as we have seen in the preceding section, makes it possible to optimize the way in which the production process is organized — can be associated with computerized planning of material and component inputs, whereas downstream, customers' orders can also be made, via the data-processing network, to mesh with the production process. A striking example in this connection is given by Fiat, which has introduced a system whereby the placing of the order with the

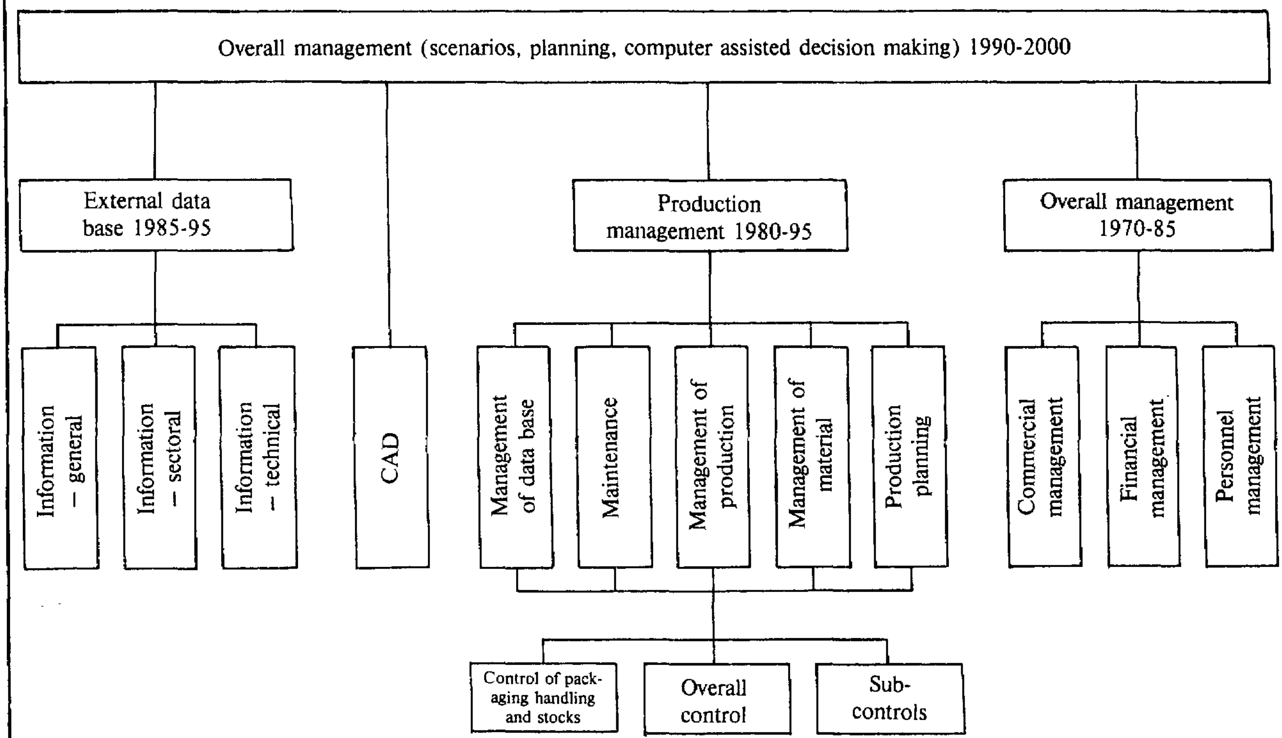
[1] According to A. D. Little: 28% in the US between 1982 and 1992.

distributor automatically triggers manufacture of the desired model.

Furthermore, computerization is also spreading to all aspects of the economic management of the firm's activities, whether they be in the accounting, commercial or financial management field.

The following table gives an insight into all these aspects.

Integrated information technology in an industrial firm



Source: BIPE.

Clearly, the benefits derived from computerization in this area vary according to the circumstances and situation of the individual firm. As far as order inputs are concerned, a computerized system installed in the Federal Republic of Germany (by Heidelberger Druckmaschinen) paid for itself within three years. As regards stocks, Arthur D. Little mentions average reductions of one-third, together with the virtual elimination of errors and shortages. Other benefits are derived as a result of the reduction in direct and indirect labour costs, the elimination of late deliveries and the general improvement in the service rendered to customers.

It should be borne in mind that some 80% of the industrial and scientific computers used in Europe were built in the United States.

Lastly, it should also be pointed out that there exists a range of specialized machines adapted to the needs of specific industries and inended to form part of automated systems (flexible centres for the injection moulding of plastics, automatic cutting machines for the manufacture of furniture, automatic sewing or knitting machines in the clothing industry, and automatic cutting machines in the footwear or clothing industry).

Computer-integrated manufacturing and the factory of the future

An attempt has been made in the preceding sections, despite numerous difficulties associated with definitions and the comparability of statistics, to portray the current situation for the different types of advanced equipment.

It is essential, however, not to lose sight of the fact that this is only a snapshot of a number of sectors which have attained different stages of development[1] and are all evolving rapidly. Thus, taking the example of FMS, this type of system is not truly profitable at the present time for the majority of potential users, but improved reliability of machines, software developments, learning effects and economies of scale should be expected in the fairly near future to bring about reductions in costs that could justify recourse to FMS by a wider range of users on economic grounds. In the case of CAD, new standard programmes are becoming more common, while the cost of terminals is continuing to fall – as indeed is that of all types of data-processing equipment. Many such examples could be given: decisions taken today should therefore not only take account of the current situation, but also bear in mind foreseeable future developments.

It should, however, also be stressed that the range of approaches and solutions available is already so varied in terms of technological standard and cost, that virtually all firms can find proven advanced equipment matching their requirements.

If the study has demonstrated that considerable increases in productivity can be achieved through the use of these different technologies on an individual basis, it should be emphasized that the real benefits emerge above all when the different types of equipment are integrated: where such is the case, individual benefits are not merely added together, they are multiplied. This leads to computer-integrated manufacturing (CIM), in which the entire industrial activity in the broad sense of the word, is managed in an integrated fashion by computer. By surveying the different sections of this first part, it is possible to identify the aspects that will go to make up the integrated factory of the future: computer-aided design of both product and process, computerized planning of external purchases and of stocks of materials and components, automated manufacturing with a tool wear measurement and tool changing system and a trouble-shooting system, automatic monitoring of product quality, automatic storage and a direct link with demand in the form of orders placed by suppliers, without forgetting computerized economic and financial management of the entire operation.

Although no factory yet exists which groups together all these functions in an integrated manner, this is no utopian dream of the distant future, since the constituent parts of such a factory are already actually operating, at different levels of sophistication, and no insuperable technical obstacle remains even though many solutions still have to be found.

As regards the benefits flowing from CIM, a recent assessment in the specialized press[2] reports an increase in productivity of approximately 250% in the case of advanced integration. Whatever the value of this type of assessment, and even if improvements in the physical productivity of the equipment are spectacular, it should not be forgotten that equally large – if not larger – gains can be made in a number of other areas. In the factory of the future, stocks – whether they consist of finished products, work in progress, or parts and raw materials – will be reduced to a fraction of what they are in a conventional factory. (In order to illustrate the impact of such a reduction: an antique dealer who takes a margin of 300%, but keeps his furniture for two years, makes less profit than a supermarket that takes only 3% but whose stocks turn in two days.) Furthermore, tool wear will be reduced by automated permanent monitoring systems (as will be machine wear thanks to automatic trouble-shooting systems), automatic quality control will lead to much lower rejects rates, while computerized control of the entire production line will bring about a substantial improvement in quality, delivery times will be shortened dramatically (the advantage of making deliveries within two weeks rather than two months is perhaps difficult to quantify, but will clearly be a decisive factor), and the introduction of new products as well as the renewal of the range of products on offer will be speeded up considerably.

These are changes which will, in the long run, revolutionize current economic conditions and the environment surrounding European firms, which will have to take up a number of technological challenges, cope with sweeping structural and financial changes and overcome the associated human problems.

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[1] See Explanatory Note 9, p. 59.
[2] *Usine Nouvelle*, third quarter, 1984.

State support for manufacturing automation (Europe – USA – Japan)

Introduction

This paper provides a resumė of measures introduced by national government for support of use and manufacture of automated production engineering equipment. The paper described measures in the Federal Republic of Germany, the United Kingdom, Italy and France, the United States and Japan.

It should be borne in mind that the paper does not take into account assistance through defence spending in Community Member States (which are more reticent than the US about assistance to manufacturing automation through this medium). Nor do they fully take into account regional (or *Länder* or US state) or export aids which exist in all the countries concerned. Incentives through the tax system are also not taken into account except in the case of Japan. Certain specific research contracts placed by governments with industry are not covered (e.g. those placed by the Federal Ministry of Research and Technology (BMFT) in Germany). In the Community context these do not currently have to be notified to the Commission. Furthermore the paper does not deal with expenditure on production automation by public bodies such as PTTs for their own benefit but which may have a wider repercussion. Finally relevant educational expenditure is largely excluded.

FR of Germany

Much of the support for manufacturing automation provided by the German government has been through the medium of broadly based programmes such as the 'Harmonization of the workplace programme' (Programm Humanisierung des Arbeitslebens). While support for use of robots was not presented as the first priority of this programme this was an important aspect. A total of DM 700 million was spent between 1974 and 1983 of which DM 100 million was devoted to robotics.

The first production technology programme (Programm Fertigungstechnik) financed research and development over a range of activities – planning of construction, layout and management systems, quality, machine control, flexible manufacturing and technology transfer. 80% of expenditure was on small firms. Expenditure was DM 163 million between 1980 and 1983 (1980: DM 39.2 million; 1981: DM 39.5 million; 1982: DM 46.1 million; 1983: DM 38.5 million) but this represented an underspend in comparison with the planned budget for the period of DM 255.6 million.

A further, revised programme 'Fertigungstechnik' was started in 1984. This programme aims at supporting development for industrial implementation of computer aided design and manufacturing, robots and related automation systems by means of grants of up to 40% of project cost (maximum grant is DM 400 000 for CAD/CAM and DM 800 000 for robots and systems). Assistance is also available for cooperation projects between enterprises and research institutes on development of machines and processes for FMS and inspection systems. Finance is also available for publications, workshops, seminars etc., training and study of such aspects as manpower requirements and working conditions. A total of DM 530 million is budgeted between 1984 and 1988 for the programme, with the following annual breakdown (in millions of DM): *1984*: 70; *1985*: 125; *1986*: 130; *1987*: 135; *1988*: 70.

The 1984-88 Fertigungstechnik programme is part of a broader 'Informationstechnik programm' for which expenditure of DM 2 960 million is planned between 1984 and 1988. Parts of this broader programme, in addition to 'Fertigungstechnik', appear to have some relevance for fostering automation and thus are likely to provide further support in this area.

The funds available are broken down as follows: DM 410 million is to be spent on fibre optics and high definition TV, with the remaining DM 2 020 million on: computer compatibility (DM 100 million), basic research (DM 100 million), peripherals in microelectronics (DM 320 million), CAD (DM 90 million), key components (DM 90 million), sub-microelectronics technology (DM 600 million), new chips (DM 200 million), CAD manufacture, new computer structure (DM 160 million) and complex data processing (DM 200 million).

Federal support for R&D comes mainly from the BMFT and is channelled through two bodies:

(i) For fundamental research, through the Deutsche Forschungs-Gemeinschaft (DFG), which groups most universities, the Max-Planck Foundation and the large scientific institutes. The DFG has an annual budget of DM 20 million for research on manufacturing automation.

(ii) For applied research, through the Fraunhofer Gesellschaft which groups 25 institutes. In particular, it gives support to the IPA (Institut für Produktionstechnik) in Stuttgart, which set up an experimental automated production system in 1977. IPA has an annual budget of about DM 65 million of which some DM 40 million came from the Federal Government and *Länder* sources. Another important institute that is supported by the Fraunhofer Gesellschaft is the IPK (Institut für Produktionsanlagen und Konstruktionstechnik) in Berlin, which also has an experimental automated system (with emphasis on testing and quality control), set up in 1976. The ISI (Institut für Systemtechnik und Innovationsforschung) is also worth mentioning: it organizes workshops and seminars dealing notably with the manufacturing automation and acts as a consultant, especially for SMEs, in this area.

Other assistance has been available or is still being given:

(i) A microelectronic programme (Sonderprogramm Mikroelektronik) providing assistance, especially for small and medium industries, for application of microelectronics. Of the 1982-85 budget of DM 450 million machine builders will receive some DM 90 million.

(ii) Provision of grants for expenditure by small and medium firms on R&D staff. A total of DM 1 407 million was spent in 1979-82 of which about 35% went to the engineering sector (i.e. DM 492 million for the period).

(iii) Provision of grants of DM 4.6 million to firms in the engineering sector for grants for external research in 1982.

Although there is little information available on this subject, the individual *Länder* are also in some cases giving considerable support to automation. In particular the Land of Baden-Württemberg has designated a commissioner for technology transfer, paying consultants' fees, offering technical consultancy through a network of 16 technology institutes, setting up technology factories, organizing training and supporting Karlsruhe University, which is in the process of establishing its own automated production system and has just opened the first production systems engineering course (what the Japanese would call 'mechatronics' engineering).

The German preference for broad-based schemes has been noted. Within these schemes there is a clear preference for R&D rather than direct investment encouragement, although, at a time of rapid technology change where increased R&D spending becomes an absolute necessity for companies' survival, distinctions between R&D and other types of expenditure lose much of their meaning.

Another point to be noted is the sharp increase in support for automation that is presently taking place. This is in fact a common feature of European countries' public support in this field.

United Kingdom

After a period in which the UK supported development and investment in specific sectors (including the machine tool (UKL 30 million programme), textile machinery and printing machinery industries) the UK has since the beginning of the 1980s tended to support usage of specific technologies although also, in some cases, their manufacture.

Thus approximately UKL 10 million was allocated to the Robot Support Programme between 1981 and 1984 to assist application and production of robots and consultancies for these activities. UKL 80 million is allocated for 1982-86 to the Flexible Manufacturing Systems scheme for support for installation of FMS and consultancies to this end. UKL 25 million of this is in fact from Support for Innovation Funds (see below) while UKL 20 million is a new allocation granted in March 1984. Since 1982 the applications section of the Robot Support Programme has been financed under the FMS scheme, and the consultancy aspects of the two schemes were merged on 1 August 1984 to form the Advanced Manufacturing Technology Scheme.

UKL 27 million is available for 1982-84 under the following three schemes:

(i) *CAD/CAM.* Feasibility studies, demonstration seminars and R&D projects in CAD;

(ii) *CAD/MAT* (Computer-aided design, manufacture and test). Grants for seminars and demonstrations;

(iii) *CADTES* (Computer-aided design and test equipment).

Application of microprocessors to products and processes throughout manufacturing industry is being assisted under the Microprocessor Application Project to which UKL 55 million was allocated for 1978-83 and to which a further UKL 20-30 million is expected to be allocated. A further UKL 55 million was received for 1978-83 for the sectoral Microelectronic Industry Support Programme which aimed to expand the UK's ability to manufacture standard and specialist integrated circuits. The UK has also recently proposed a UKL 25 million scheme for take up of advanced equipment by the textile industry.

The two SEFIS (Small Engineering Firms Investment Scheme) programmes provided UKL 130 million between 1981 and 1984 for one third grants for small firms to buy NC machine tools and some other items of advanced equipment.

Grants for R&D are available from Support for Innovation Funds which apply generally to manufacturing industry. Some of the funds are allocated to specific programmes (e.g. parts of robot and FMS schemes) but assistance has been given to automation outside the medium of specific schemes, e.g. to the machine-tool and welding equipment industries. The Mechanical and Electrical Engineering Requirements Board (MEERB) also provided R&D support to the engineering sectors in general. Funding in the field of CAE was, for example, UKL 5.1 million in 1978-79 and UKL 2.3 million in 1980-81. This funding was granted by a predecessor of the MEERB, the Mechanical Engineering and Machine Tools Requirements Board. The MEERB is now an advisory body in connection with overall funding of CAE. Research into future generations of robotics is financed by the Science Research Council through a UKL 2.5 million programme of joint industry/university research which commenced in 1980.

The UK has general provisions for investment encouragement outside specific sectoral or technology based schemes. It is difficult to ascertain the amount of funding involved for manufacturing automation, but, for example, UKL 4.3 million was provided for establishment of a Unimation robot manufacturing facility in the UK.

Thus the UK has a large number and wide variety of schemes. An increasing preference for technology based rather than sectoral schemes is discernible, although the latter continue to exist and be proposed.

Investment assistance predominates (although frequently, for instance under the FMS scheme, investment is associated with development) but assistance remains available for R&D. While most programmes are specific in nature, funding procedures of a very general type exist. However it is difficult to determine to what extent these provisions are used to fund automation.

Italy

Italy does not have the profusion of support measures for automation that exist in other countries. The 'Sabatini law' enacted in 1965 allowed for deferred payment of up to five years for purchase of machine tools but figures for the amount of assistance involved are not available. There are three relevant programmes under the overall 'Progetto Finalizzato' framework of the National Research Council for which it is believed that LIT 56 000 million has been allocated:

(i) 'Informatica': LIT 13 000 million was made available for work on advanced process control, CAD in mechanical engineering and machine interfacing.

(ii) 'Technologie Meccaniche': This programme has a budget of LIT 30 902 million for 1983-88. Concentrating on manufacturing technology its main objective is the development of machine tools and their integration into flexible manufacturing systems. There are three sub-programmes: flexible systems, integrated technology and components and industrial experimentation (prototype site). From the technological point of view the laser represents an important part of the programme which will be managed by the CNR and involves a close liaison between research centres and industry.

(iii) 'Robotica': It is not known if this programme has gone beyond the feasibility study stage.

Two general funds are of relevance. The Fund for Innovation which supports introduction of technological developments leading to new or improved products or processes stood at LIT 1 600 000 million for 1981-83. This fund applies to the automobile, electronics, iron and steel, aeronautics and chemical industries.

Law 696 of 19 December 1983 has taken over from the Sabatini Law and has now become a major vehicle for the support of manufacturing automation. This law, under which LIT 100 million has initially been made available (taken from the Fund for Innovation), provides for a subsidy of 25% of the cost (not including VAT) to SMEs of buying or leasing advanced manufacturing equipment.

The IMI special fund for applied research stood at an amount of LIT 1 700 000 million for 1982-83, which was available in grants and loans. This fund applies to all of industry.

France

France has a wide variety of measures for support for automation and advanced equipment relating both to industry sectors and to technologies.

The machine-tool plan provides for expenditure of FF 2 300 million for 1982-85. Its aim is to restructure the machine-tool industry and make it internationally competitive, through development contracts whereby companies agree to fulfil certain targets related to investments, R&D, capital increases, retraining, etc., in exchange for access to public funds. These in fact come from existing institutions and funds, such as Anvar, etc. The machine-tool plan also provides for coordination of the various public agencies involved in technological innovation and assistance for purchase of NC machine tools and advanced equipment by educational establishments.

There have been a series of public agencies and programmes aiming to encourage innovation and investment:

(i) 'Robotics billion': an FF 1 200 million programme for favourable loans for purchase of robots during 1982-85.

(ii) MECA procedure which permits small and medium firms to test automated equipment and finances subsequent acquisition. FF 500 million has been allocated for 1982-85 (of which FF 150 million in 1982). The procedure is run by the Agence Nationale pour la Développement de la Production Automatisée (Adepa).

(iii) DAP (Développement de l'automatisation de la production) encourages innovation in automation by small and medium enterprises and has a budget of FF 14 million in 1981 and FF 20 million in 1982.

(iv) Efficacité des équipements et maîtrise des débouchés: The fund which stood at FF 2 500 million in 1982 encourages investment programmes through favourable loans of up to 70% of expenditure.

(v) Codis (Comité des Industries Stratégiques) provided credits for selected companies in selected areas of technology. There was a concentration on FMS. In 1982 the fund stood at FF 110 million and was projected to stand at FF 455 million in 1983 and FF 715 million in 1984.

(vi) PUCE (produits utilisants des composants électroniques) has a budget of FF 40 million for 1983-84 to encourage small firms to incorporate electronics in their products.

(vii) Special loans to industry. Soft loans of FF 30-70 million to industry for application of equipment in line with national priorities (including production automation).

FIM (Fonds Industriel de Modernisation) was created in 1983 to provide favourable loans to users for modernization of manufacturing processes and development of new products. It also takes into account office technology and biotechnology. FIM has taken over the activities of Codis and possibly DAP and the fund 'Efficacité des équipements et maitrise des débouchés'. Only FF 1 000 million was spent out of FIM's 1983 allocation of FF 3 000 million. The remainder was brought forward to 1984 as part of a total allocation of FF 7 000 million. It has recently been reported[1] that another FF 1 000 million has been added to top up the fund.

A 'programme productique' for 1983-86 has been launched; it functions along the same lines as the 'plan machines-outils', i.e. through the use of development contracts providing for privileged

[1] *Financial Times*, 9.8.1984.

access to existing funds, such as the FIM as well as a training programme, assistance to supply of equipment through Codis contracts and stimulation to public and private research. FF 100 million has been allocated to this latter aspect but details of other financial arrangements are as yet unknown.

The following assist R&D:

(i) ARA (Automatisation Robotique Avancée) coordinates some 50 research laboratories and 20 large companies for research on FMS and robotics. FF 5 million was budgeted for 1981, FF 15 million for 1982 (another FF 15 million derives from another agency) and the programme lasts until 1985.

(ii) Anvar (Agence Nationale pour la Valorisation de la Recherche) had a budget of FF 200 million in 1983 (out of a total of FF 900 million) for aids to innovation for production of advanced equipment in the field of manufacturing technology.

Thus France has a large number of arrangements for funding in similar fields concentrating both on technologies and industry sectors of general and specific types and dedicated to users and producers. It should be stated that budgets relating to these financing arrangements have not always been fully drawn on. The FIM funds were not fully spent in 1983.

United States

The Department of Defence has a Mantech programme with expenditure as follows (in millions of dollars): 1978: 118; 1979: 126; 1980: 139; 1981: 156; 1982: 209; 1983: 300 (estimate from non-US source).

A significant part of this programme is managed by the US Airforce with the overall purpose of assisting productivity in the aerospace industry and developing advanced manufacturing technology. The USAF programme has the following sub-sectors:

(i) generic manufacturing technology;

(ii) ICAM (integrated computer-aided manufacturing);

(iii) manufacturing science;

(iv) technical modernization;

(v) airforce logistics command initiative.

The importance of ICAM is worth noting. Among other activities it includes a demonstration project at Boeing – the Integrated Sheet Metal Centre (ISMC). This will incorporate the features of the four areas of emphasis in ICAM – systems development, information management, planning and control and product and process definition. The purpose of the ISMC is to demonstrate and validate the benefits of computer-aided integration of quality assurance, production planning and control in batch manufacturing and to show clearly the size and source of these benefits.

The following sums are involved in the USAF programme (in millions of dollars): 1980: 56; 1981: 69; 1982: 84; 1983: 95; 1984: 108.

As much expenditure as possible is made through placement of R&D contracts with private equipment producers. There is a system of dissemination and exchange of results, thus implying general benefit to the civilian sector.

In addition NASA spends some USD 2 million per year on research into robotics.

Other government bodies are active in research. The National Science Foundation has devoted the following sums to basic research in automation (in millions of dollars): 1980: 2.5; 1981: 2.8; 1982: 3.1; 1983: 3.5; 1984: 4.6.

The Foundation's small business programme cost USD 2.8 million in 1981 and USD 3.1 million in 1982 for research into grinding and optical gauging. Finally the Center for Manufacturing Engineering of the National Engineering Laboratory, which comes under the National Bureau of Standards, spent USD 5.6 million in 1982, USD 5.4 million in 1983 and USD 11.1 million in 1984, on basic research into automation. This involved development of advanced NC systems, as well as setting up a fully automated research facility, to enable the NBS to develop interface standards for integrating advanced equipment, and also to act as a test-bed for these standards.

In a recent study[1] the Office of Technology Assessment of the US Congress has presented a table showing how much of the various programmes mentioned above are devoted to automation and

[1] 'Computerized Manufacturing Automation – Employment, Education and the Workforce'.

splitting them between military and civilian subtotals, although the importance of this distinction should not be exaggerated in view of the substantial civilian fall-out from military programmes.

Federal funding of R&D in programmable automation – fiscal year 1984

(USD Mio)

Military agencies:	
Mantech programme	56.00
Defence Advanced Research Projects Agency (Darpa)	3.50
Office of Naval Research	4.10
Military subtotal	63.60
Civilian agencies:	
National Bureau of Standards (NBS)	3.85
NASA	5.90
National Science Foundation (NSF)	6.90-9.20
Civilian subtotal	16.65-18.95
Total Federal funding	80.25-82.55

Source: OTA.

This description, however, relates only to Federal funding, and takes no account of support from individual states, about which we have practically no indications. It is also worth noting that the practical effects of military development contracts can go far beyond the R&D stage, since military orders often provide subsequently a large, stable market for the product that has been developed. This very real support cannot be quantified.

Japan

The Japanese Government provides certain tax incentives, which because they are specific to machinery are described here. It should be borne in mind however that tax incentives to industry are a common form of support in the industrialized countries dealt with in the paper, but are elsewhere not so specifically targeted and are hence not described under other country headings. From April 1978 special depreciation in addition to the ordinary depreciation, amounting to 14% of the acquisition cost has been allowed for machinery and equipment including industrial robots purchased by small businesses capitalized at yen 100 million or less.

From the same date special initial depreciation, in addition to ordinary depreciation, amounting to 10% of the cost of acquisition of designated products in the case of users and 10% of the value of capital investment for manufacture of designated products in the case of manufacturers has been allowed. The designated products are important machinery system components including industrial robots and CNC machine tools. A special rate of 25% was applied between financial years 1978-79 and of 13% between 1980 and 1981. Under this scheme an estimated yen 40 000 million of tax relief was given in financial year 1978. Since April 1982, under the Mechatronics Investment Promotion Tax System for Small Business, special initial depreciation, in addition to the ordinary depreciation, amounting to 30% of the acquisition cost or tax exemption equivalent to 7% of the acquisition cost in the accounting year of purchase, with an allowable exemption limit of 20% of the amount of corporate tax in the same year has been given to small firms capitalized at yen 100 million or less for acquisition of products in the area of mechatronics machinery and computers. Tax exemption equivalent to 7% of 60% of a total lease commitment value in the accounting year of lease with an allowable exemption limit of 20% of the amount of corporate tax for the same year is provided for lease of products in the same areas. An estimated yen 27 000 million of tax relief is being given under this system in the 1984 financial year.

The Japanese authorities provide incentives to users and manufacturers of automated production equipment in the form of low interest loans. The Small Business Finance Corporation has from April 1980 provided loans of up to yen 300 million per enterprise capitalized at yen 100 million or less or with a total of 300 employees or less over a 13-year period with a five-year grace period at 7.1%

p.a. for the first three years and 7.6% p.a. thereafter. The loans are for purchase of equipment enhancing industrial safety and hygiene, including designated industrial robots. In the 1983 financial year, yen 11 651 million was given for 556 projects. The People's Finance Corporation has from April 1980 given loans on the same terms and for the same purpose of up to yen 33 million per enterprise capitalized at yen 10 million or less or with a total of 100 employees or less. In the 1983 financial year, yen 1 410 million was lent for 201 projects. Under the Small Business Facilities Modernization Fund established in April 1980 prefectoral governments provide no interest free loans, half subsidized by the State to small businesses (100 employees or less) for purchase of machinery and equipment contributing to modernization. The maximum loan amount is yen 15 million per enterprise and the maximum loan period is five years. In the 1982 financial year, yen 38 789 million was lent for 6 855 projects.

The Japanese Development Bank provides loans to large businesses capitalized at more than yen 100 million or with a total of more than 300 employees) for certain types of capital investment for manufacture of products designated by MITI. These include industrial robots and selected NC machine tools, for which interest rates at the most favourable rate under the scheme of 7.1% are available for loans of 50% of project costs over a 10-year period with two years of grace. The loans have been available from September 1978 and yen 16 800 million was provided in the 1983 financial year. The Small Business Finance Corporation has since September 1978 extended its loan system to capital investments aimed at manufacturing the products designated by MITI for the Japanese Development Bank loans.

Business capitalized at yen 100 million or less or with a total of 300 employees or less are eligible. The maximum loan amount is yen 300 million, but otherwise the terms are the same as those for JDB loans. In the 1983 financial year, yen 1 290 million was given for 12 projects.

The Japanese authorities also assist hire purchase and leasing of capital equipment. Under the Small Business Modernization Fund non-profit-making prefectoral leasing institutions have since April 1980 purchased industrial robots and loaned them to small businesses with 20 employees or less on a hire purchase basis. The maximum loan value is yen 20 million per enterprise, the maximum period of redemption is 54 months while the hire rate is 5% of the outstanding debt. In the 1982 financial year, yen 14 676 million was spent on 1 725 cases. In April 1980 leading manufacturers of industrial robots created the Japan Robot Leasing Company (Jarol) with financial back-up from the Fiscal Investment and Loan Programmes of the Japanese Government. This leases industrial robots and flexible manufacturing systems made by 66 leading Japanese manufacturers to businesses capitalized at yen 10 million or less or with a total of 1 000 employees or less. In the 1983 financial year approximately yen 10 000 million was expended.

The Japanese Government also provides domestic credit insurance schemes. The Machinery Credit Insurance System for Instalment Sales and Loan Sales Contracts inaugurated in June 1961 is designed to cover sellers' risk accompanying instalment sales of or banks loans for sale of 25 types of machinery including industrial robots. The premium is 0.83% of the sales value for a 36-month insurance of industrial robots. A Machinery Credit Insurance System for Lease Contracts was established in June 1961 to cover the lessor's risk accompanying the lease of 32 types of machinery including industrial robots. In the case of industrial robots the maximum insurance period is 37 months and the premium is 0.363% for a 36-month insurance. In the 1983 financial year, the insured amount under the above two schemes was yen 519 000 million. A further government scheme is the Credit Extra-Insurance System of the Small Business Credit Insurance Corporation which insures debt guarantees made by Credit Guarantee Societies to small businesses and credit guarantees extended to loans associated with the 'Elevation programmes' drawn up by MITI in the light of the Law for Promotion of Machinery, Electronics and Software Industries (see below). The maximum insured value is yen 30 million, coverage is 70% and the premium is 0.57% p.a. In the 1983 financial year the insured amount under this scheme was yen 5 505 000 million.

Up to 1970 technological support on the production automation area aimed at Japan's catching up of front runners in machine-tool technology, production facilities and industrial structure.

Subsequently the Law for Promotion of the Machine-Tool and Electronics Industries (1971-77) shifted the emphasis to 'mechatronics'. Under this law, especially in the 1976-77 period, MITI produced 'Elevation programmes' for various NC machine tools. These programmes set out technological requirements, projected market size and investment volume and provided for tax area financial incentives (these are among the measures described above), joint R&D activities and exemption from anti-monopoly law. These measures enable development and commercialization of products and production facilities in an atmosphere of confidence and with reduced initial risk. The 1971-77 law was replaced by the Law for Promotion of Machinery, Electronics and Software Industries, 1978-85. MITI has now become less concerned with targeting and prefers to construct 'visions' as a base for policy measures. These present structural information about an industrial sector and indicate the basic direction of medium or long-term policy, but it is up to industry how to interpret or use a 'vision'.

MITI's research project – 'Research and Development of FMS with Laser' – is now in its final stage. The work is undertaken by a private association specifically established for the task and consisting of 20 private companies (9 machine-tool companies, 4 from heavy industry (especially forging) and 7 companies from the electronic industry. Three MITI laboratories are also involved). A total number of 400 researchers is involved. The total budget is some yen 13 700 million 1977-84, for which yen 1 197 million is allocated for the 1983 financial year and yen 627 million for the 1984 financial year. The association is now conducting its final project – the practical use of its test plant, a self-contained automated gear box manufacturing facility.

The Advanced Robot Technology Research Association (Artra) was founded in February 1984 to undertake the MITI project – R&D Project of Robots for Critical Work – in cooperation with MITI's research institutes and universities. This aims to develop technologies necessary for a new type of sophisticated robot capable of deep sea and nuclear plant work and of rescue work in disasters. Six firms from heavy industry, 8 electrical and electronics companies, 2 industrial associations and 2 robot-makers are participating. Some yen 20 million is budgeted for an 8-year period.

The research associations of the Ministry of Contruction started a project in 1983 entitled 'Consruction Robots and Automated Systems' for development of a prototype automated construction system. The 1983 financial year budget was yen 10 million, that for the 1984 financial year is yen 40 million. A further MITI project is for 'R&D of Automated Sewing Systems'. This has a budget of yen 130 000 million for 1982-89 with an allocation of yen 717 million for the 1984 financial year. This involves a total computerized system for sewing preparation, sewing and assembly, fabrics handling and production control.

Local government plays a role in technological development as is apparent from the prefectoral involvement in some of the schemes noted above. Most local governments in Japan also maintain technological research facilities including facilities for mechanical and metallurgical engineering. MITI has established the 'Inter-Industries Cooperation Scheme' in 1984 which provides yen 3.5 million to each 'inter-industry association' for which local governments must pay half the subsidy. There are 14 such associations of which at least two are in the production technology area (one for development of robots for under-water work; the other for R&D precision dies production technology).

Japanese industrial assistance is therefore usually targeted to particular sectors and is characterized by financial incentives to the purchase of production equipment by users; for enhancement of manufacturing facilities of manufacturers of advanced production equipment and for clearly defined and closely coordinated R&D projects.

Conclusion

The FR of Germany, the UK, Italy, France, the US and Japan all have significant public aids to manufacturing automation. The US, while it has some civilian publicly financed R&D, is different to the other States in channelling the bulk of its funding through defence spending. Italy has by far the lowest funding and fewest schemes although the general nature of these schemes makes it difficult to determine exactly what funding is devoted to automated production equipment. France and the UK both have a large array of schemes with different targets and Germany concentrates on a few broad-based schemes.

Japan has a large number of schemes but these can be grouped into a very few similar types and have common targets. Japan's State funded R&D is much more closely coordinated and targeted than that in the other countries – certainly the Community countries – and is not dominated by military requirements as in the US.

Tables and figures

Table 1 – **Main difficulties encountered by British microelectronics users[1] (1983)**

(in %)

General economic situation	43
Lack of qualified staff	39
High development costs	29
Lack of funds for development	30
Higher production costs	15
Software problems	14
Problems with sensors	10
Difficulties in communicating with subcontractors or suppliers	9
Problems with microelectronic chips	7
Opposition from workers or trade unions	6
Opposition from management	4
Opposition from other groups	4

[1] Industrial firms employing a workforce of more than 20.

Source: PSI.

Table 2 – **Barriers to innovation in German industry in 1982**

Data given as a percentage of replies (multiple replies possible)

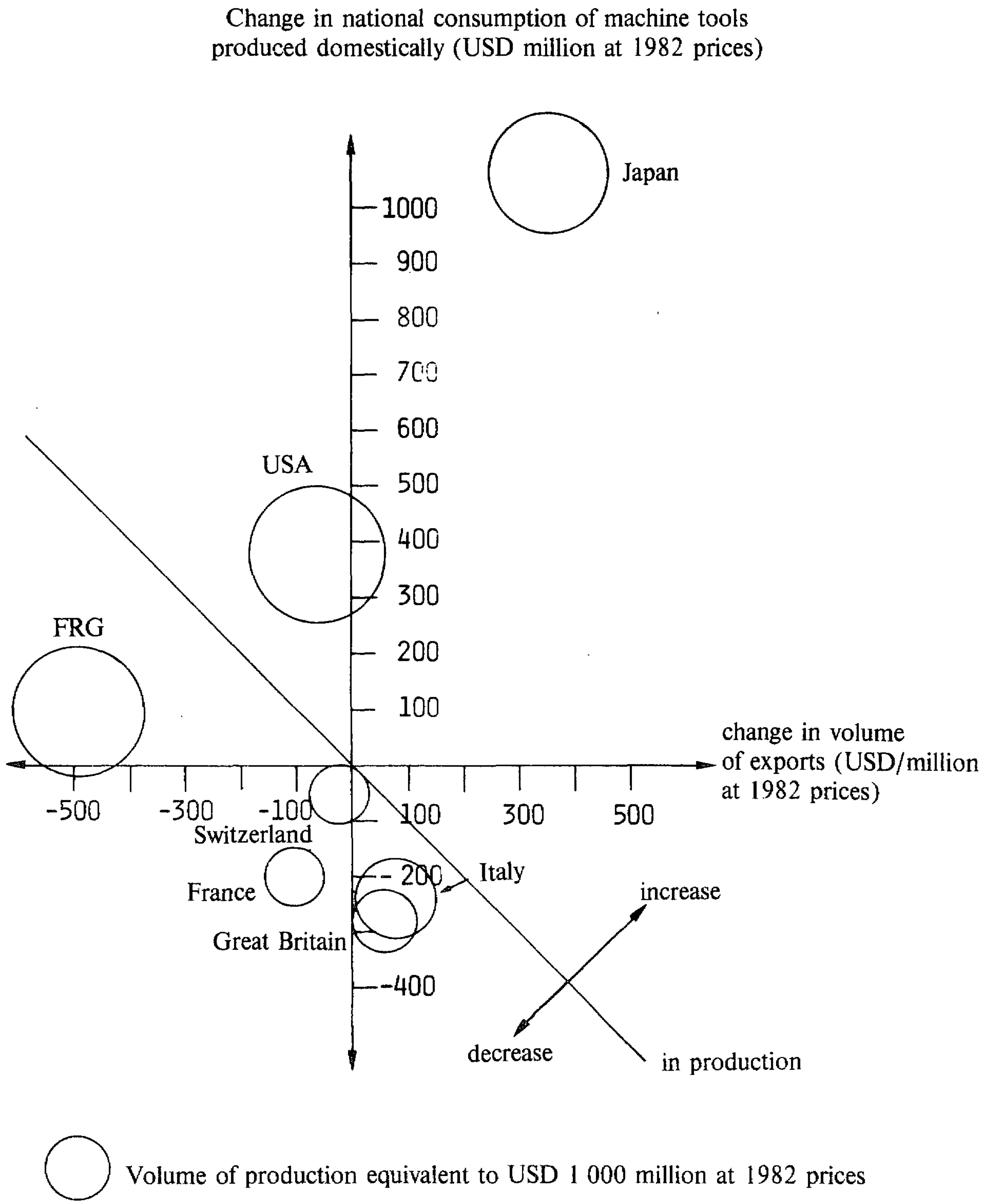
Barriers to innovation	All firms in the processing industry: Non-innovating[1]	All firms in the processing industry: Innovating	Including machine-tool industry[2]
Lack of equity capital	50	30	47
Access to external finance	17	5	13
Insufficient profitability of the innovation made, as a result of:	70	76	80
– excessively high development costs	49	48	58
– excessively long amortization period	19	45	25
– market uncertainty	74	69	58
Internal resistance to innovation	15	10	20
Organizational problems	7	14	–
Difficulty in finding staff qualified in the field of:	13	24	40
– R&D	64	80	100
– Production	31	27	–
– Sales	27	28	–
Problems in converting technical know-how into saleable products	13	16	27
No opportunity for innovation since the technology has reached maturity	7	11	7

[1] Defined as firms which have not introduced any innovation in 1982.
[2] Firms defined as innovating.

Source: IFO.

Figure 1

The causes of the variation between 1977 and 1982 in the production of machine tools in the different producing countries



Volume of production equivalent to USD 1 000 million at 1982 prices

Source: Boston Consulting Group.

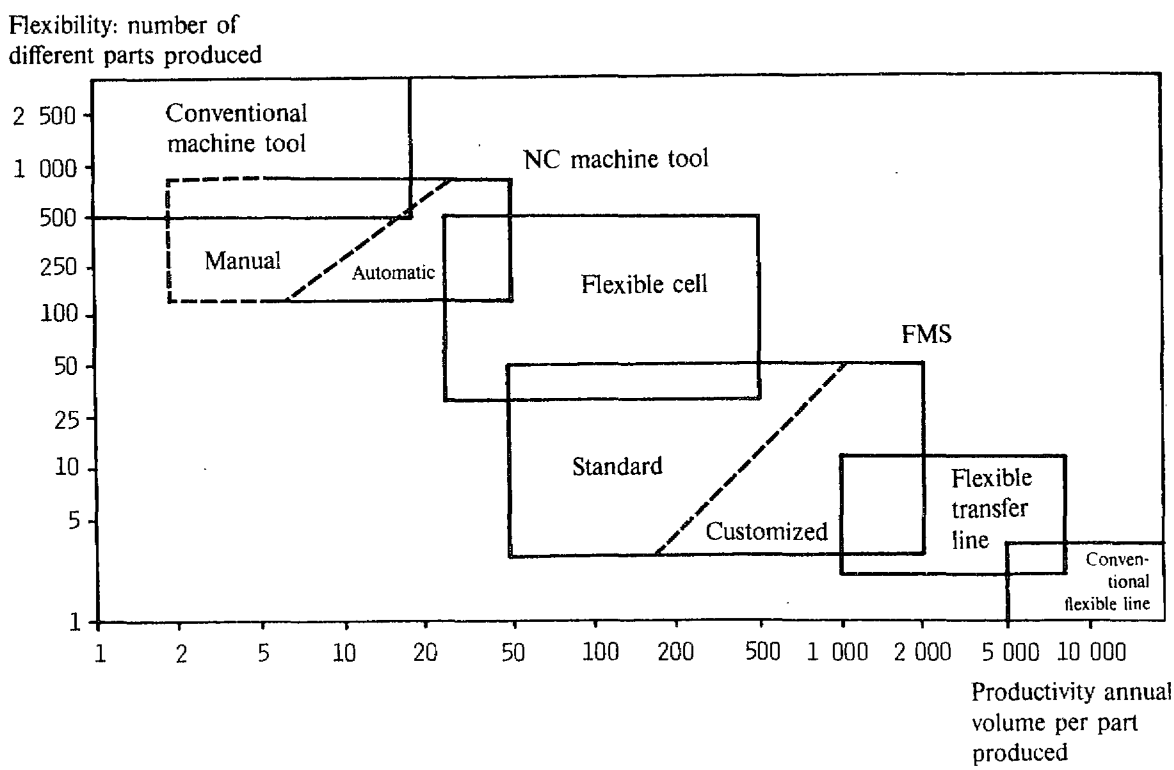
Table 3 – **Forecasts for the annual growth of the industrial robots market**

Japan	1980-85: 35-40%	(Bacho, Halsey Stuart Shields)
	30%	(JIRA)
	10-20%	(CREI-Lettre 2000)
United States	1980-85: 35%	(Wall Street brokers)
	26%	(CREI-Lettre 2000)
	1980-95: 36%	(Predicast)
Sweden	1979-84: 20%	(Swedish Computers and Electronics Commission)
	1985-90: 17-26%	(ibid)
	1981-86: 26%	(Creative Strategies International)
France	1980-85: 27-35%	(Diebold)
	1985-90: 21-24%	(Diebold)
	1981-86: 49%	(Creative Strategies International)
United Kingdom	1981-86: 58%	(Creative Strategies International)
FR of Germany	1981-86: 46%	(Creative Strategies International)
Italy	1981-86: 56%	(Creative Strategies International)
Australia	1982-90: 30%	(Australian Science and Technology Council)

Source: OECD.

Figure 2

Productivity and flexibility of the different types of advanced equipment and system



Explanatory notes

1. On the basis of the NACE industrial classification, the following categories are regarded as having discontinuous processes:

31 Manufacture of metal articles
32 Mechanical engineering
33 Manufacture of office machinery and data-processing machinery
34 Electrical engineering
35 Manufacture of motor vehicles and of motor vehicle parts and accessories
36 Manufacture of other means of transport
37 Instrument engineering
43 Textile industry
44 Leather and leather goods industry
45 Footwear and clothing industry
46 Timber and wooden furniture industry
47 Processing of paper and board
48 Processing of rubber and plastics
49 Other manufacturing industries

2. **Size of the market for advanced manufacturing equipment**

According to a report by BIPE (Bureau d'informations et de Prévisions Economiques) carried out on behalf of the French Ministry for industry, entitled 'la Productique et les Industries Manufacturières' and dating from December 1982, the French advanced manufacturing equipment market totalled FF 8 000 million in 1982. By extrapolation based on France's share of Community added value from non-continuous industrial processes (about 20%), this gives a Community market of close to 6 000 million ECU in 1982.

According to IPA in Stuttgart (Fraunhofer Institut für Produktionstechnik und Automatisierung), the six main German industries using production line assembly (mechanical engineering, motor industry, electrical engineering, instrument engineering, manufacture of metal articles and manufacture of office machinery) are at present allocating on average 25% of their capital expenditure to the assembly side, 40% of this going to automation. By 1987 these percentages are likely to rise to 29% and 50% respectively. A more general idea is given by the IFO which shows that at the present time almost 60% of capital investment by processing companies in Germany is going to the introduction of new production processes or new techniques.

According to a Financial Times survey published on 12 January 1984, it is likely that by 1990 more than USD 100 000 million (128 000 million ECU) will be spent in Western Europe and North America on automating manufacturing industry. Assuming that the EEC accounts for 40% of this total, it will be spending about 51 000 million ECU on automation over the next six years.

3. A recent survey by the PSI in London shows that in the United Kingdom 94% of British companies with a workforce exceeding 1 000 use microelectronics in their manufacturing process, while the corresponding figure for companies with a workforce of from 500 to 1 000 is 83%.

The same survey shows that British companies with a workforce of over 1 000 use three times as much microelectronics in their manufacturing process as small firms with 20 to 49 employees.

4. This study dating from September 1983 was carried out by Professor Wassily Leontief on behalf of the National Science Foundation and contains three scenarios for the spread of automation. The analysis is based on a series of detailed input-output tables for each sector of the US economy.

5. As can already be seen from the tables set out on pp. 41 and 42 (Annex I) European manufacturers are unquestionably making an effort to modernize their machinery and equip it with numerical control. It should be noted that the acceleration in the pace at which numerical control is being installed corresponds fairly closely to the termination of the Siemens-Fanuc exclusive distribution agreement for numerical controls following the action taken by the Commission of the European Communities. Termination of this agreement is said to have enabled a substantial reduction to be made in the cost within the Community of Fanuc numerical controls, which represent 50-60% of the world market.

Furthermore, press reports and European successes at recent machine tool exhibitions are signs of marked progress in the incorporation of microelectronics in European machine tools.

6. Similar results were forecast by a study carried out by Consultronique on behalf of the Commission, dated December 1981. The following annual average growth rates were forecast for the first half of this decade:

(%)

	in value terms	in units
Community production		
All NC machine tools	19	17
World production		
All NC machine tools	17	12
Machining centres	24	15
NC lathes	16	10

The French plan for machine tools predicted – admittedly, on the basis of resolute government action – that the size of the French NC machine tools market would increase from 10 500 units in 1981 to 26 500 units by 1985, representing an annual growth rate of 26%.

All these forecasts have proved inaccurate, as a result of the unexpected seriousness of the recession, which has caused an overall drop in European production of some 30% in value terms between 1980 and 1983. Nevertheless the share of NC machines in the total number produced has continued to increase considerably, while European production of this type of machine has continued to grow slightly, despite the recession. In view of the widespread upturn in the demand for machine tools which began to make itself felt in 1983, average annual growth rates of approximately 20% for NC machines in the Community as a whole during the years ahead do not therefore appear unreasonable.

More specific indications should shortly become available on this topic, since the results of surveys coordinated with that of the Policy Studies Institute and carried out according to the same methods should be available for France and the Federal Republic of Germany by the end of 1984.

7. Definitions of robots

ISO: 'The industrial robot is an automatic position-controlled reprogrammable multifunctional manipulator having several axes and capable of handling materials, parts, tools, or specialized devices through variable programmed operations for the performance of a variety of tasks'.

Robot Institute of America (RIA): 'A robot is a reprogrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.'

UK Department of Trade and Industry: 'A robot is a reprogrammable mechanical manipulator.' Nevertheless, according to the British Robot Association, 'an industrial robot is a reprogrammable device designed both to manipulate and transport parts, tools or specialized manufacturing implements through variable programmed motions for the performance of specific manufacturing tasks.'

The JIRA
(Japanese Industrial Robot Association) defines five categories of robot:

1. Manipulators: devices controlled directly by an operator.

2. Sequential robots: manipulators operated according to a pre-established sequence:
(i) a fixed sequence: a sequence that cannot be easily modified;
(ii) a variable sequence: a sequence that can be readily modified.

3. Playback robots: manipulators which store in their memory a sequence demonstrated by the operator.

4. NC robots: manipulator robots which receive instructions from a numerical controlled station.

5. Intelligent robots: robots capable of understanding the tasks required of them thanks to the capacities of a sensor and means of recognition.

The majority of the devices belonging to the first two categories are not regarded as robots according to the other definitions set out in the foregoing.

Definition according to categories of application: The list of applications is extensive and includes the following in particular:

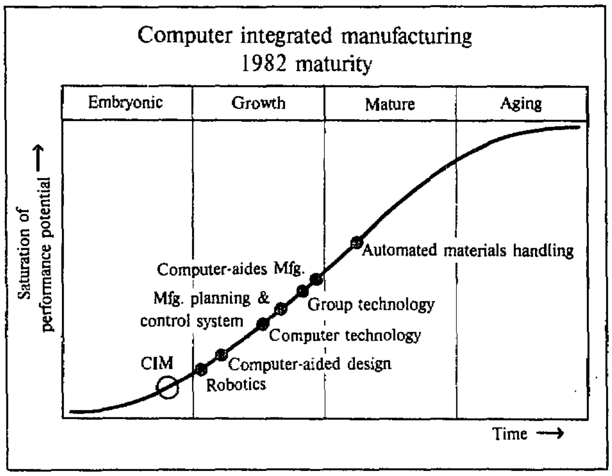
- spot welding
- arc welding
- surface treatment
- heat treatment
- paint spraying
- injection moulding (of plastics)
- dye-casting
- investment casting
- assembly
- palletizing and packing
- handling and transfer (loading/unloading of machine tools)
- pressing
- foundry work
- forging
- measurement and inspection

Each of these applications requires slightly different robot configurations and specifications, as regards the arm geometry, the propulsion system, dynamic performance and precision, reliability and safety.

Arm geometry may be classified into four major types: geometries with Cartesian, cylindrical or spherical coordinates and articulated robots. The propulsion systems are generally pneumatic for light work, hydraulic for heavier work and electrical for precision work.

8. In its survey of automation dated 12 January 1984, the *Financial Times* takes the view that on average, CAD systems multiply productivity by a factor of three. A. D. Little estimates the multiplication factor at between three and four.

9. A graphic description of the stages of development of the different technologies concerned has been set out in the following table by Arthur D. Little.



Glossary

NC	Numerical control
CAD	Computer-assisted manufacture
CAM	Computer-assisted manufacture
CAE	Computer-assisted engineering
CIM	Computer-integrated manufacturing
FMS	Flexible manufacturing system
MAP	Manufacturing Automation Protocol (of GM)
AMRF	Automated Manufacturing Research Facility
OSI	Open Systems Interconnection (of ISO)

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This communication to the Council takes stock of the impact of industrial automation. It contains a Commission statement on advanced manufacturing equipment and a detailed analysis of the situation and outlook of the sector. The paper was written in response to a request made by the Ministers for Industry at an informal meeting in Paris on 18 May 1984.