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INTEGRATED MANUFACTURING*

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* The views expressed in this document are those of the authors and do not necessarily reflect the views of the Secretariat of UNIDO. This document has not been edited.

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EXPLANATORY NOTES

Reference to "dollars" ($) are to United States dollars.

Reference to "pounds" (£) are to pounds sterling.

Mention of firm names and commercial products does not imply the endorsement of UNIDO.

The following acronyms have been used:

AGV	Automated Guided Vehicle
AIMS	Advanced Integrated Manufacturing System
AMT	Advanced Manufacturing Technology
CAD	Computer-Aided Design
CAD/CAM	Computer Aided Design and Manufacture
CAPM	Computer-Aided Production Management
CAPP	Computer-Aided Process Planning
CIM	Computer-Integrated Manufacturing
CMM	Co-ordinate Measuring Machinery
CNC	Computer Numerical Control (usually applied to machine tools)
DFM	Design for Manufacture
DNC	Direct Numerical Control
DP	Data Processing
EDI	Electronic Data Interchange
FMS	Flexible Manufacturing System
IAT	Integrated Automation Technology
ISO	International Standards Organization
IT	Information Technology
JIT	Just-In-Time Production (or scheduling)
LAN	Local Area Network
MAP	Manufacturing Automation Protocol

MPS	Master Production Schedule
MRP	Material Requirements Planning
MRP2	Manufacturing Resources Planning
NC	Numerical Control
OPT	Optimized Production Technology
OSI	Open System Interconnection
PC	Personal computer
SABU	Semi-Autonomous Business Units
SPC	Statistical Process Control
TOP	Technical and Office Protocol
TPM	Total Preventive Maintenance
TQC	Total Quality Control
VLSI	Very Large Scale Integration
WIP	Work-in-Progress

SUMMARY

The study is part of UNIDO's continuing review of technological advances and their potential and implications for the industrial development and policy approaches of developing countries.

Recent advances in manufacturing technology such as Flexible Manufacturing Systems, Computer-Integrated Manufacturing and Robotics are in essence complex and interactive systems. Developing countries may be faced with having to import turnkey and inappropriate systems unless they have the capacity to disaggregate and build their own systems, enabling them to import or produce relevant equipment with the required degree of systems integration.

Against this background, the study examines the use of Advanced Manufacturing Technologies (AMT) and new approaches to the organization and management of manufacturing operations in the quest for flexibility. The focus is primarily in the advanced industrial nations but with a view to presenting options to developing countries.

The study begins with a look at the organizational and technological context in which changes are taking place and considers the limitations likely to confront developing countries in their access to technologies and their capacity to assimilate them. The technological options now available in the key activities in manufacturing - design and pre-production, production itself and the overall co-ordination and management of the process - are presented and the ways in which integrated technology can change the nature of linkages between firms on both the supply and distribution side are discussed.

The fact that these technologies exist does not mean, however, that they are easy to install or manage. Thus, the experience so far with these technologies is reviewed, covering the diffusion across different economies and the costs and benefits that have emerged so far. The sources of supply for such automation technologies and the type and limitations of assistance they can provide to potential users are also outlined.

Since successful implementation of integrated automation often seems to require alternative organizational approaches - in structures, patterns of work organization, skill levels and distribution - the theme of organizational innovation is taken up, exploring the experience so far with new approaches to production organization and management such as "Just-in-Time" and "Total Quality Management". Evidence suggests that many of the problems of demand for greater flexibility and efficiency can be dealt with using approaches that emphasize investment (via training) in human capital rather than advanced technology. This is not to argue that these approaches should be seen as alternatives but as complementary to options in technological innovation. Possible programmes combining organizational and technological change are looked into.

The discussion moves on to a general strategy for exploring the opportunities offered by new automated technologies and organizational techniques, stressing the need to take a long-term view and building up capacity and experience in increments rather than taking a "Big Bang" approach and trying to effect radical change too quickly. The requirements for developing countries interested in evolving a strategy for Computer-Integrated Manufacturing - in terms of awareness raising, skills and resource development and building up local technological capacity - are analyzed.

The study does not mean to suggest that all developing countries will wish to adopt these technologies, or that they necessarily should. It would, however, be to their advantage to monitor developments, increase awareness and develop some experience in the techniques available in order to make more appropriate choices.

Finally, the report takes up some of the key policy issues in implementing integrated manufacturing technology, particularly at the firm and national levels. The report concludes with recommendations for UNIDO activities, including demonstration projects to illustrate the potential of the new technologies for improvements across the range of manufacturing activity.

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INTRODUCTION

The competitive environment

1. Advanced industrial nations

Whether their markets are local or international, manufacturers today are faced with a set of competitive international pressures to produce to a suitably low price in an effort to capture and defend their market share. Intensifying the competition are new entrants from lower-cost producers, with recession a factor as well. In addition to the new pressures, there are the usual problems of rising costs of inputs such as labour, materials and energy. Not surprisingly, customers are in a position to demand high quality, more consistently reliable products and better delivery performance.

It is these pressures - both price and non-price - that are setting the context in which advanced technologies are being developed. Firms are having to deal with demands for:

(a) Price reduction, or at least price maintenance at low levels;

(b) Non-price factors such as design and quality;

(c) Customer service before, during and after sales;

(d) Greater customization of products, more variety and differentiation;

(e) Shorter product life cycles to cater for markets with an increasing "fashion" orientation;

(f) Short delivery response times.

To provide greater variety in products with more frequent modifications, and to meet the demands for customer-specific service, firms are finding it necessary to become more flexible.

Flexibility extends to:

(a) Coping with fluctuations in demand;

(b) Offering a wide range of products tailored to suit individual customer requirements;

(c) Introducing new products more frequently;

(d) Ability to use the same item of capital equipment for more than one product.

Instead of easing the competitive environment, however, increased flexibility intensifies it with an accompanying set of different problems. Every time a new product has to be made, production equipment must be stopped, reset and restarted - a sequence which can take hours or even days.

Problems of flexibility include:

(a) Low machine utilization (due to set-up times for different batches);

(b) Queuing problems at key "bottle-neck" operations through which all products must pass;

(c) Low machine utilization due to queuing upstream and waiting downstream of bottle-neck operations;

(d) High inventory levels of raw materials, work-in-progress and finished goods;

(e) Long production lead times;

(f) Poor production monitoring and control;

(g) High overheads in indirect staff engaged in trying to monitor and expedite orders;

(h) Poor delivery performance;

(i) Poor quality;

(j) Inefficient use of space;

(k) Overloaded paperwork systems.

Traditionally, there has been a trade-off between productive efficiency and flexibility. Under ideal conditions, firms would prefer to produce a small range of products in high volumes and concentrate on high productivity at the expense of flexibility. This strategy stresses economies of scale and heavy capital investment in dedicated equipment - such as is found in the process industries. But market pressures are now forcing firms to try and find alternative ways of producing with high flexibility <u>and</u> high productivity.

The pressures to become more sensitive to individual customer needs is not confined to consumer product manufacturers but is spreading across the industrial spectrum. Nor is it confined to the small batch sector where there have always been problems in the trade-off between flexibility and productivity. Even the high volume process industries, such as petrochemicals or food processing, are now beginning to look to ways of coping with smaller "packets" in response to much more specific demand (1).

This phenomenon is specific to particular advanced industrial countries. With some variation, this general pattern is common to all manufacturing nations. Table 1 presents the results of a survey on manufacturing futures conducted by the international business school INSEAD, which regularly asks senior manufacturing executives about their key problem areas and their strategic responses. The study, drawn from research on more than 500 firms, reveals that competitive priorities - particularly for firms in the USA and Europe - depend considerably on achieving the kind of "manufacturing agility" just described.

Table 1. Comparison of competitive factors in manufacturing, 1986 (listed in order of priority)

Europe	USA	Japan
Consistent quality	Consistent quality	Low prices
High performance products	High performance products	Rapid design changes
Dependable deliveries	Dependable deliveries	Consistent quality
Fast delivery	Low prices	Dependable deliveries
Low prices	Fast deliveries	Rapid volume changes
Rapid design changes	Rapid design changes	High performance products
After-sales service	After-sales service	Fast delivery
Rapid volume changes	Rapid volume changes	After-sales service

Source: INSEAD, Manufacturing Futures Survey, 1987.

2. Developing countries (2)

Clearly, there are important differences between developing and developed countries in terms of the sources of competitive pressures. Firms in many developing countries are currently struggling under restrictions placed on obtaining foreign currency as a consequence of international debt. Others have seen hard-won markets restricted, doors closed to new entrants or the competition simply "hotting-up" as advanced industrialized nations respond to import penetration.

Where developing countries are trying to expand their share of world markets, the same demands on firms from advanced industrial nations will apply. With increased emphasis on non-price factors, the ability to produce at lower price, while still important, is not as much of a competitive advantage as previously. Even where price is still the dominant factor, improvements in the productivity of firms in developed countries may eventually offset labour cost differences as competitiveness moves away from a labour cost basis to countries able to offer high quality, high technology products, fast delivery and high rates of new product introduction. The pressure on firms in developing nations to increase their own flexibility will be unrelenting.

This pressure for flexibility will be felt not only by export-oriented firms. Firms whose attentions are directed at local markets have always been faced with smaller markets and fluctuating demand. As currency restrictions continue to inhibit commodity and capital goods purchases from international markets, the pressure and opportunities for local firms will increase.

Notes

1. An example is the growing use of "mini-mills" in the steel industry.

2. The treatment of developing countries (and, for that matter, developed countries) as a homogeneous group in this report is purely a function of available space. The report recognizes that in many cases differences within such groups are as large as those separating them.

I. THE TECHNOLOGICAL CONTEXT

Into this picture of increasing competitive pressures must now be added the powerful range of new technologies based on programmable automation which have become available during the 1970s and 1980s. These technologies (discussed in detail in Chapter II) address some of the problems currently facing manufacturers. For example, programmable technology permits more rapid changeover of plant to make different specifications and products and increases flexibility. This can be accomplished without necessarily incurring the traditional cost penalty in productivity terms due to unproductive set-up times. At the same time, the increasing use of computer-based systems for co-ordination greatly facilitates production management activities such as planning, scheduling and keeping track of a larger number of smaller batches.

Individually, each of the new programmable technologies represents a powerful tool offering important benefits to discrete areas of manufacturing such as design or machining. However, it is the increasing convergence of these technologies and the subsequent integration of activities within the plant that represent such a significant advance over most previous generations of manufacturing innovation. The ability to integrate technologies and manufacturing activities arises primarily out of the opportunities created by the fact that most activities in manufacturing are, at heart, information-based. That is, they involve some combination of storing/retrieving, processing and communicating information.

For example, a machine controller takes in information (communication) about the state of the process it is controlling. It then compares this with other information in its memory about the desired state (storage/retrieval) and calculates (information processing) the necessary corrective action. Finally it sends information (communication) back to the process to bring it back into line. Since systems for different activities within manufacturing operate on the same basis - using digital representation of information - there is enormous scope for linking them together into highly integrated systems.

Thus, the traditionally separated (but often extensively automated) functional areas of manufacturing - such as design or quality control - are being brought closer to manufacturing, while the overall co-ordination process for production is increasingly being linked to other business functions. The emerging model is one of Computer-Integrated Manufacturing (CIM) in which all the functions of a manufacturing business are not only automated in themselves, using some form of computer system, but also integrated with each other via a range of networks and communications software.

A. Technological options

The various options open within CIM can be examined by considering the manufacturing organization as made up of three spheres of activity (1). The main activities within these spheres and the associated technological changes that are taking place are discussed.

1. Design and pre-production

This activity includes all the tasks necessary to identify, describe and prepare products for manufacturing. The process begins by converting concepts to some form of physical representation of the product to be made.

Following this outline design stage are many stages of draughting, increasing the level of detail until a final set of instructions, codified on a suite of engineering drawings, can be given to the production area for actual manufacture. At the same time the requirements for particular operations and for materials, components and sub-assemblies must be identified and communicated to the production and materials management areas.

The extent of design activity varies with industrial sector and with both firm size and company strategy. In chemicals, for example, there is clearly little product design but considerable emphasis on process design and on research and development work to support this. By contrast, a capital goods manufacturer will work closely with individual customers, producing new designs or modifying existing drawings to meet a particular requirement. The development of a new product like a car can involve thousands of drawings, produced and held not only by the final assembler but by the many hundreds of component suppliers as well.

2. Production

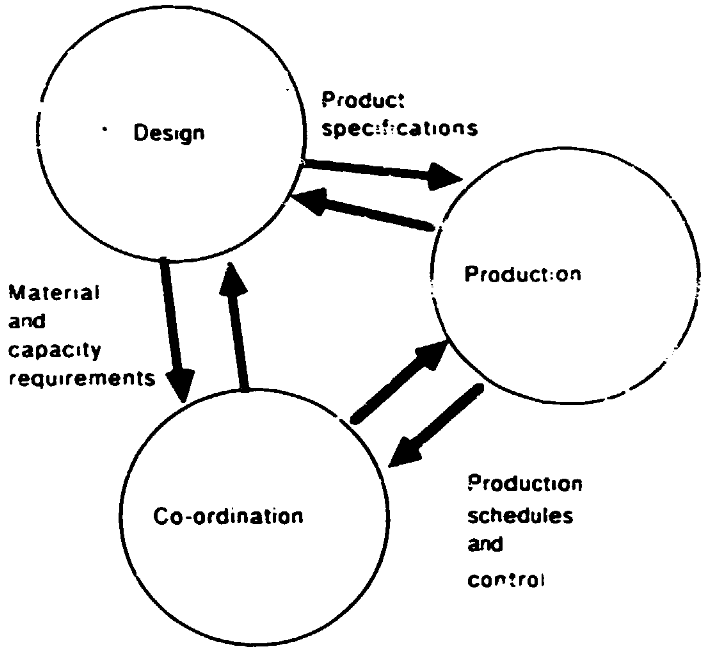
In production, the information from design is translated via a series of operations into physical form. The range of operations varies enormously but covers not only actual operations (such as mixing, moulding, cutting, grinding, drilling, pressing and various types of assembly) but also handling and manipulation, transport, storage and retrieval, and testing and inspection. It also covers the operation and maintenance of the production facilities.

3. Co-ordination

Finally co-ordination involves the various managerial tasks needed to support the manufacture of the product from initial design activity through to sales and distribution. This ranges from order processing, material and capacity requirements planning, production monitoring and control, expediting and progress chasing, cost accounting, and marketing and distribution.

Figure I illustrates clearly that these three spheres are extensively interrelated in terms of the information necessary to flow between them. It is for this reason that CIM is so significant, providing the technology to make radical improvements to the way such interrelationships are managed.

Figure I. Three spheres of manufacturing



The range of automation equipment and systems available within this pattern is wide but can be classified effectively by considering different levels of integration in automation. Figure II indicates a simple classification along these lines.

Figure II. Levels of automation

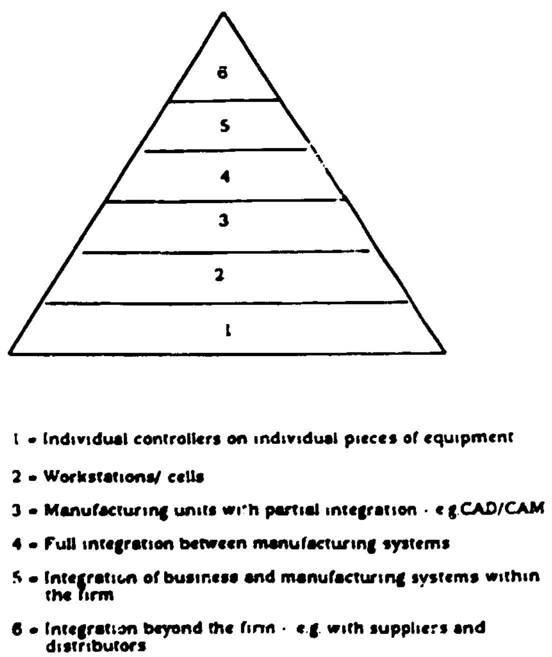


Figure III illustrates this in simplified fashion, taking the case of metalworking as an example. Initially, technological trends were largely confined to integrating basic tasks within this particular sphere of manufacturing - for example, bringing together a variety of discrete machining tasks into a single CNC (Computer Numerical Control) machining centre. The next stage was to integrate between the various activities - for example, between handling, manipulating and machining of workpieces in a machining cell, and by co-ordinating these under a supervisory shop-floor computer. At the highest level there is integration between spheres of activity - for example, by bringing design and manufacturing together by means of CAD/CAM (Computer Aided Design and Manufacture) linkages, or co-ordination/planning and manufacture within a Flexible Manufacturing System (FMS).

Figure III. The trend towards integration in metalworking

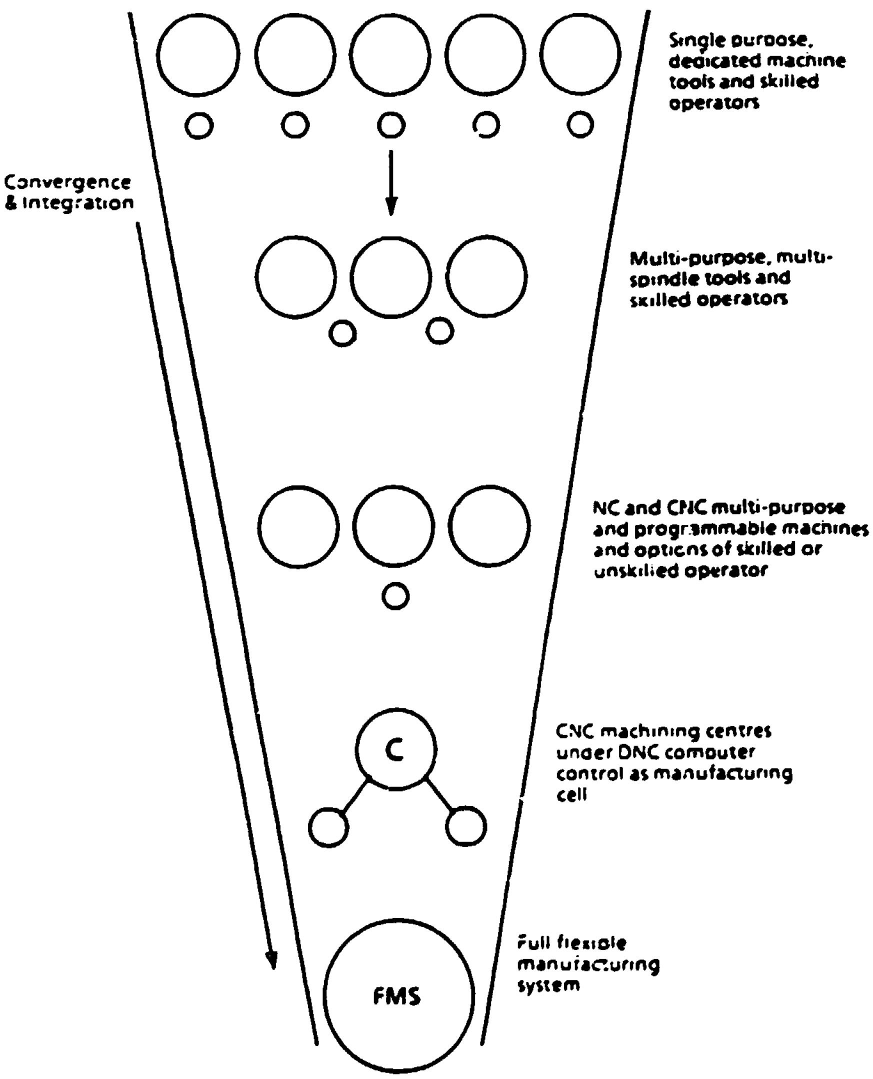
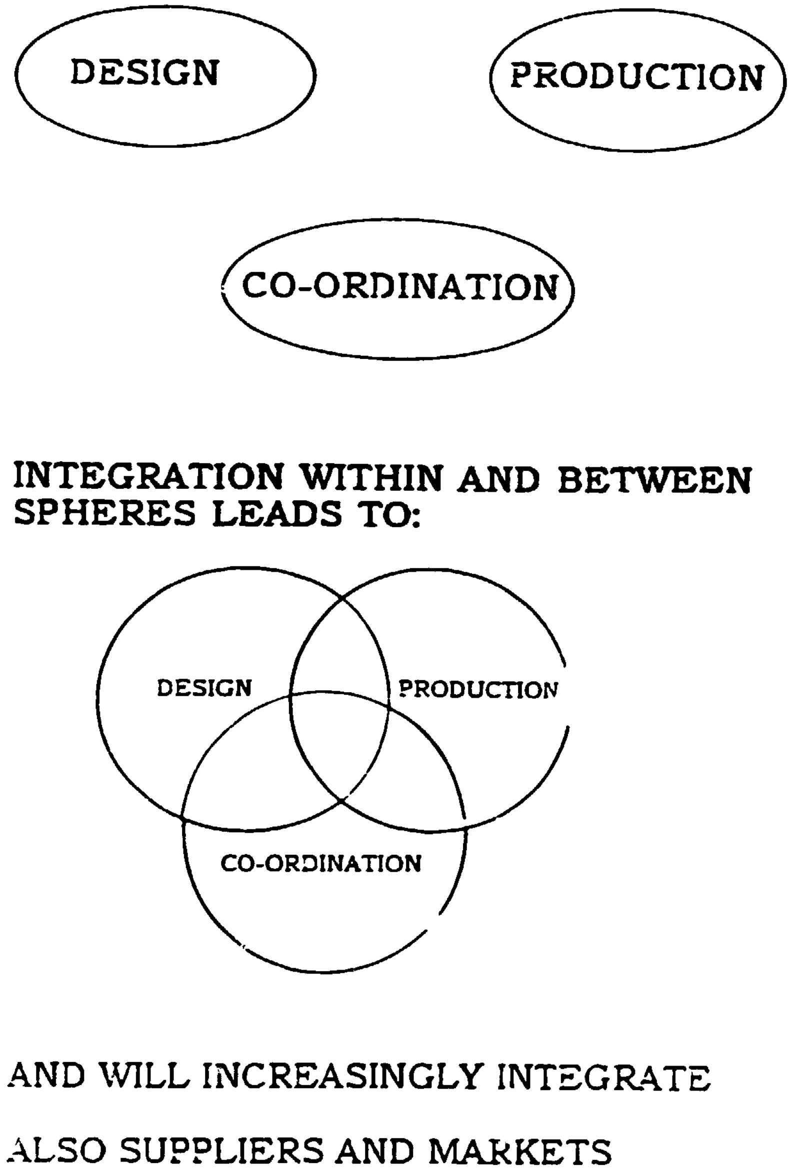


Figure IV indicates how this pattern is reproduced across the whole factory, so that integration within different spheres eventually forms the basis of what has been called Computer-Integrated Manufacturing.

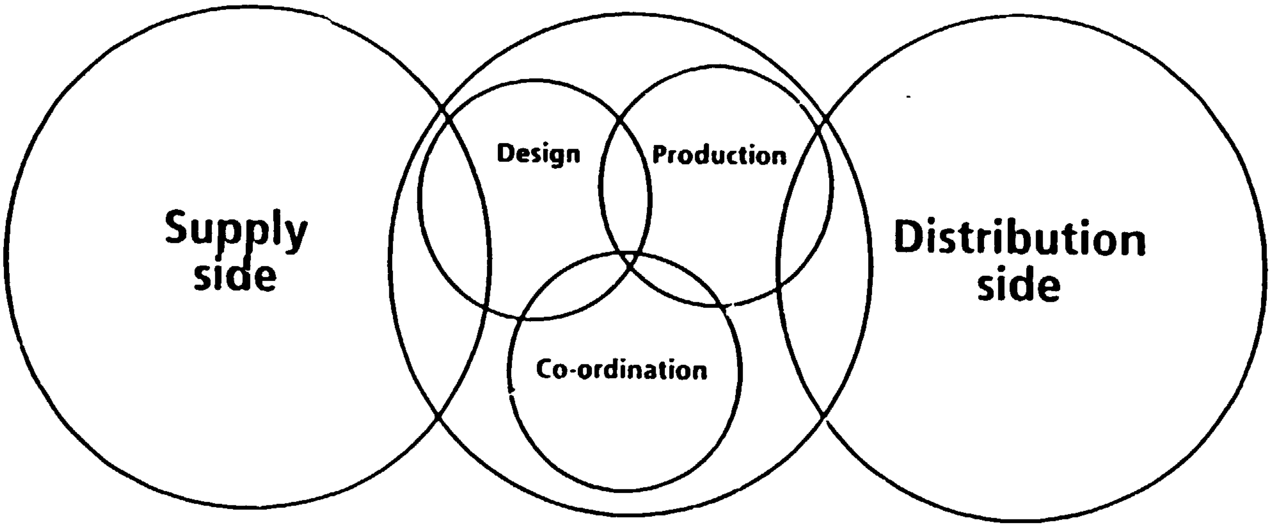
Figure IV. The trend towards full Computer-Integrated Manufacturing



It is also worth noting that the pattern of integration does not need to stop at the boundaries of the firm; linkages between firms - on design, purchasing, distribution, etc. - are also possible via similar computer communication networks. The Digital Equipment Corporation (DEC) for example, in a recent report describing its Clonmel CIM facility in Ireland, points out that through the use of the company's world-wide computer/communication network, the plant can access up to 15,000 computer systems. For a task like design, this means that a vast resource of specialized knowledge - distributed geographically throughout the world - can be brought to bear on the problems of a particular plant through a single computer terminal and appropriate communications software (2).

Figure V indicates a typical vision of such a CIM facility, in which the result is a highly responsive and productive plant with linkages extending beyond the boundaries of the plant or firm.

Figure V. Integration within and beyond the firm



Such integrated facilities attract interest primarily because they offer radical improvements in a number of traditional problem areas confronting manufacturers. It is useful to compare these with the list of problems mentioned at the start. They include:

(a) Reduced lead time, both for existing and new products;

(b) Reduced inventories, especially of work-in-progress;

(c) More accurate control over production and better quality production management information;

(d) Increased utilization of expensive equipment;

(e) Reduced overhead costs;

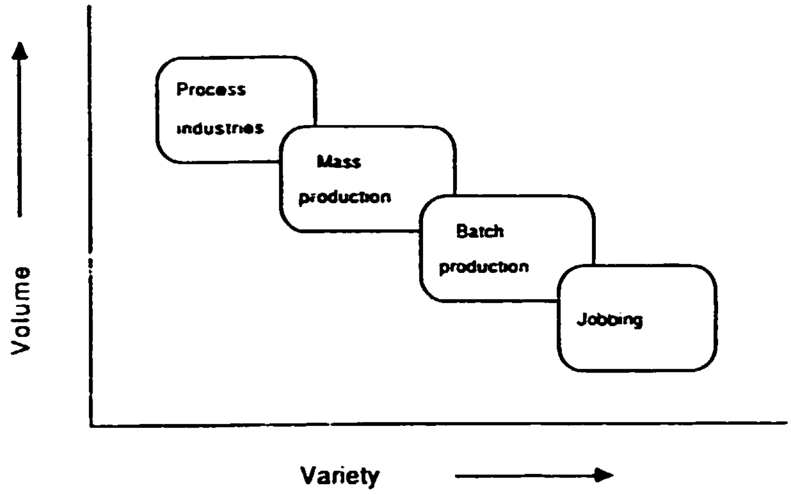
(f) More reliable delivery performance;

(g) Better quality management.

B. The pattern across the industrial spectrum

At the same time as the demands for increased flexibility are spreading, the potential applications of such integrated automation are also extending right across the industrial spectrum. This represents a major change from earlier generations of automation which were confined to larger scale and high volume industries. Figure VI classifies manufacturing activities into four general areas, along the lines of volume and variety of products.

Figure VI. Manufacturing activities (volume and variety)



In the high volume/low variety businesses, the pressure has traditionally been to try and produce as much as possible as cheaply as possible while maintaining quality standards. Emphasis was placed on productivity. This was achieved through extensive capital investment and automation; economies of scale were critical to success. However, the pattern is changing and the pressures now are for greater flexibility and agility, even in commodity-type businesses. As a result, major firms in these industries are exploring and investing extensively in CIM. Examples include margarine and edible oils production (where the demand for low fat and low cholesterol products has forced a shift away from volume to variety), synthetic fibres (where similar trends in the clothing industry have pushed the industry towards shorter production runs) and chemicals. In food processing, even commodity products like sugar are beginning to be sold in high variety, lower volume configurations. Here, most of the flexibility is required in the finishing and packaging stages rather than in the direct processing.

In the mass batch industries, the pattern has been for approximations to flow processes through the use of expensive special-purpose equipment (such as transfer lines) and powerful models of production organization and management (such as Henry Ford's production line concept). Attempts to achieve scale economy traditionally led to the use of expensive automation of the "hard-wired" (3) variety.

However, as has been indicated, the pattern is now changing. Increasing use is being made of programmable controls, robotics and flexible manufacturing systems; CAD/CAM; and other technologies. At the same time, organizational changes are leading to smaller workforces and plants producing with greater flexibility and quality through the application of alternative management approaches such as Just-in-Time (JIT) manufacturing and Total Quality Control (TQC).

One effect of this is that the pattern of competitive advantage may shift. Some firms are attempting large-scale CIM ventures of a highly complex nature (such as in the General Motors Saturn project), aimed at high volume production. But others (e.g. the UK's Rover Group) are trying to use integrated manufacturing as a means of survival as a small but flexible producer (4). Once again this supports the view that CIM and related approaches may open up new opportunities based on economies of scope rather than simply of scale.

Although these changes are perhaps most evident in the engineering industry, they are by no means confined to it. In the field of semiconductor production, for example, the pressure has been growing for high quality, rapid product changes and growing variety to suit user-specific needs. This has led to growing integration in the manufacturing process - for example, of design and manufacturing via CAD systems linked to scanning and stepping-projection lithography, ion implantation and vapour deposition equipment. Statistically process control has been integrated throughout the process and there is also close linkage between the design stage and the later automated test equipment (5).

In the case of small batch manufacturing - such as in capital goods or aerospace - the opportunities opened up by CIM are considerable. Traditionally, the more different batches a firm produces, the more difficult their manufacture is to manage. Forecasting sales is harder, achieving a balance between overstocking raw materials and production hold-ups is difficult and keeping track of products at various stages in manufacturing is complex. As a result, guaranteeing deliveries is problematic. Moving through several different production stages often gives rise to unbalanced operations with bottlenecks and underutilization of plant. Some estimates suggest that in many metalworking plants, products spend only 2 per cent of their time within the factory actually being worked upon - the rest being wasted in waiting to get on to the machinery, or in being pushed aside to allow higher priority items through, in being "lost" somewhere in the system, and in finished product stores awaiting orders. This can represent a huge amount of capital tied up and being unproductive. It is suggested, for example, that in the UK the investment in inventory, much of it as work-in-progress, is about £23 billion.

Such complications and uncertainty in the production process mean that lead times (from receipt of customer orders to delivery) are often overly long; consequently, delivery is hard to guarantee. Attempts to resolve the problem by employing progress chasers and other indirect workers to expedite production adds further to the high manufacturing cost.

As more variety is introduced into the product range, these problems become exacerbated. With much engineering production taking place in batches of less than 50 items (6), the attractions of integrated automation technologies such as CIM and FMS, which offer both productivity and flexibility, are considerable. Although, as has been mentioned, there are examples of CIM across a wide spectrum of industries, the high diversity involved in the batch engineering sectors is reflected in the concentration of much of the current interest in Advanced Manufacturing Technology (AMT).

However, even at the extreme end of this spectrum - very high variety, very low volume production - there are still attractions in some aspects of integrated automation. In those industries where there is a high degree of sub-contracting, for example, the possibilities of enhancing flexibility and responsiveness through the use of CAD/CAM and CNC in the hands of a small number of highly-skilled craftsmen has considerable attractions. Notably several small firms in Scandinavia have begun to exploit the opportunities opened up by such "flexible specialization" to enter and defend small market niches in engineering and capital goods (7).

In considering the technological context, it is also important to mention the contribution offered by new approaches to the organization and management of production - such as Just-in-Time and Total Quality Control. Chapter VI discusses these in detail.

Notes

1. For a discussion of this model, see R. Kaplinsky, Automation: The Technology and Society (London, Longmans, 1984).

2. B. O'Malley, "Why bother with CIM?", B. Hundy, ed., Proceedings of 5th International Conference on Automated Manufacturing (Bedford, UK, IFS Publications, 1987).

3. This term refers to early generations of automation using electronics based on physical connections between elements in the control system. Changing the program required changing the physical wiring and other elements and was thus inflexible.

4. See D. Altschuler and others, The Future of the Automobile (Cambridge, Mass., MIT Press, 1985).

5. For a detailed review of these trends, see Microelectronics Monitor, No. 21 (1987) (UNIDO publication).

6. Estimates suggest that around 75 per cent of engineering production takes place in such small batches. See, for example, the discussion in Computerized Manufacturing Automation (Washington, D.C., Office of Technology Assessment, 1984).

7. See, for example, P.-H. Chistenson, Industrial Models in the Melting Pot of History: Report to FAST Committee (Denmark, Roskilde University, 1986).

II. COMPONENTS OF MANUFACTURING AUTOMATION

Although CIM has received widespread publicity, the overwhelming majority of automation projects world-wide have so far concentrated on relatively low levels of integration. Examples would include programmable controllers on individual machines, stand-alone CAD workstations or relatively simple manufacturing cells based on a CNC machining centre with associated handling equipment.

By contrast, a full CIM facility would involve integration of all aspects of the manufacturing process with those of the business, extending beyond to the supplier and marketing/distribution chains. Systems of this kind are rare; most are small-scale demonstration facilities (such as have been shown at major automation exhibitions in the USA and Europe) or prototype plants on which potential users can try out different options and anticipate early problems.

In putting together such systems, a number of component technologies are being used. The major components fall broadly within the three spheres of manufacturing activity as Table 2 shows.

Table 2. Components of manufacturing automation

Design	Production	Co-ordination
* Computer-aided draughting and design	* Robotics	* Computer-aided production management software including material requirements planning and manufacturing resources planning (MRP2)
* CAD/CAM processing (production of control information for automated production equipment from design data held on computer	* Flexible manufacturing systems	* Expert systems for planning and project management
	* Advanced materials handling systems	* Factory automation and communication networks
	* Automated warehousing	
	* Automated test equipment	
	* In-process gauging and sensing	

A. Individual components

1. Computer-Aided Design (CAD)

The principle of Computer-Aided Design dates back to the early 1960s and to U.S. work on defence applications. Early experiments demonstrated the potential for improvements in draughting activities but progress was severely limited by the high costs and computing power requirements involved. Use of expensive mainframe systems was confined to a few industries: electronics (where new design tools were needed to support the increasingly complex task of achieving VLSI (very large scale integration), aerospace, vehicles and cartography.

The basic principle of CAD is simple. Instead of representing information about a product, component or process layout on a paper drawing, it is held as digital information within a computer memory and displayed on a screen. This image can be processed in different ways and information can be output either as a physical drawing (via a printer) or as electronic information which can be processed further - for example, by another CAD system or by a computer-controlled manufacturing system.

Options in CAD extend far beyond basic draughting into areas such as sophisticated interactive graphics in three dimensions, simulation programs, analytical techniques (such as finite element analysis) and other elements that enable rapid and thorough exploration of different design options.

In general, CAD supports all phases of the design process, which are:

(a) Conceptual design;

(b) Preparation of drawings (draughting);

(c) Engineering calculations;

(d) Preparation of parts lists;

(e) Generation of production planning information;

(f) Links to other systems such as NC programming.

The industry really took off in the early 1970s with a number of innovations, including the emergence of mini-computers (which could provide the necessary processing power at lower cost), the Tektronix display tube, and new programming tools and techniques.

Quickly, usage increased in terms of industrial sector (with considerable expansion in engineering in particular), firm size (with many smaller firms entering the field) and geographical region (with a move away from the concentration of systems in the USA).

A second surge of growth came in the early 1980s with the emergence of low-cost microcomputer-based systems based around the IBM PC and compatibles. Packages such as Autocad offered considerable CAD power for prices within the reach of almost all firms. Although relatively low down the market share table in value of units sold, Autodesk (the manufacturers of Autocad) sold considerably more than any other manufacturer during 1986 - over 100,000 units world-wide.

The position now is very favourable for the potential CAD user. Systems are available from a wide choice of suppliers (estimated at over 500 in the USA and Europe) offering a range of capabilities from simple, 2-D draughting through to complex 3-D surface and solid modelling, finite element analysis and calculation/communication of control programs for automated manufacturing equipment.

Within the firm, the appearance of CAD has had a marked impact on the nature and organization of the design process (1). The main effect so far has been to integrate the traditional activities in the drawing office into the CAD workstation. Productivity of this stage can be considerably enhanced with a figure of 300 per cent often being quoted - although experience varies widely and depends on the task being carried out. For modifications and basic draughting, this can often be exceeded but for other tasks, such as originating designs, the level is nearer 1:1 in comparison with manual systems. There is, however, a danger in assessing CAD systems in terms of extra capacity to generate drawings. The wider advantages of CAD, which must be considered when measuring benefits, often include the ability to work with fewer drawings.

In a recent survey (2) of experience in the Federal Republic of Germany, among the motives firms gave for implementing CAD were to:

(a) Reduce lead times in responding to customer orders;

(b) Reduce time taken to make modifications;

(c) Reduce new product development lead times;

(d) Improve utilization of raw materials;

(e) Improve quality and accuracy of design;

(f) Simulate and investigate alternative options;

(g) Improve tendering and overall image to customers;

(h) Reduce errors in complex design;

(i) Improve drawing office productivity.

Perhaps the most important point to emerge here is that CAD is clearly not a technology introduced purely for labour-savings in the drawing office but a product of a much wider set of objectives. In a number of cases - particularly in the clothing industry - CAD systems have been introduced as a means of overcoming skills shortages (3). However, it is still most commonly justified on the basis of improvements in design/draughting labour productivity.

In general, most of these CAD users reported benefits which met or exceeded their expectations - although these did not often emerge as rapidly as had been expected. The general view was that there is a significant learning period associated with getting the best out of the technology - one which increases with the complexity of the system in use.

Another interesting feature was the emergence of unforeseen benefits. For many firms, systems had been bought in the expectation of reducing lead times or increasing design productivity, but additional benefits emerged.

These included improvements in the competitiveness of the firm as a result of the image they were able to present to potential customers by producing drawings rapidly; by being sufficiently flexible to incorporate customer changes and new specifications; and by being able to offer a shorter lead time in new and standard product development.

Improved design quality was also an important feature that resulted from being able to simulate and explore different design options quickly and extensively. This was achieved in two ways. First, reductions in lead time meant that more time was available to explore alternative design options. Second, the availability of powerful simulation tools meant that this time could be usefully exploited to produce higher quality final designs.

Although impressive, these are relatively minor benefits compared with the potential opportunities CAD opens up for integration of the design process across the whole company. For example:

(a) CAD/CAM systems permit the generation of designs and the relevant information necessary for controlling the manufacturing operations themselves - in the process removing the barrier between drawing and conversion of that information into control instructions for machining, assembly, etc. Benefits arising from this include significantly reduced lead times, less wastage of raw materials, improved quality, reduced rework and higher machine utilization. In addition, the benefits of CAD/CAM extend beyond product design to the range of fixtures and handling systems, and can also be used to assist in planning and optimizing routing through the plant. In turn, this opens up the possibility of more flexible working with smaller batch sizes.

(b) CAD linkages with the Computer-Aided Production Management (CAPM) system permit more rapid and accurate generation of data such as the bill of materials in a Material Requirements Planning (MRP) system (see below). This can automatically be updated when product specifications change or when new products are introduced. The creation of an electronic description of the product (and its accompanying fixtures) in the CAD system provides a common data base on which various other software programs can draw for their particular production management requirements.

(c) CAD links with marketing permit a rapid response to customer requirements. Required changes or features can be quickly added to an existing design and the instructions passed through to manufacturing via a direct CAD/CAM linkage. The overall lead time is reduced and this improved responsiveness on time and customer specificity contributes considerable marketing strength.

(d) CAD links with testing and quality management allow for the development of test procedures and equipment that provide a more reliable feedback loop so that quality problems picked up anywhere in the process can be diagnosed and design changes incorporated with a minimum of delay.

(e) As integrated systems become more commonplace in manufacturing and production management, so the possibilities for full Computer Integrated Manufacturing are opened up. Many commentators on CIM developments agree that the logical basis for a CIM system is a common data base of information about the product on which the various systems draw - and the CAD system provides the natural focal point for generating and maintaining this data base.

2. Industrial robotics

As with CAD, robotics has had a long history but has only really become an important force since the emergence of low-cost programmable automation, enabling "intelligence" to be built into what are essentially sophisticated manipulating machines. The International Standards Organization (ISO) defines an industrial robot as "an automatically controlled, reprogrammable, multi-purpose manipulative machine with several degrees of freedom which may be either fixed in place or mobile, for use in industrial automation applications".

This broad definition covers a growing range of applications, from heavy duty robots, which replace human strength in repetitive activities such as unloading die-casting machines in the foundry industry, to delicate and sensitive assembly robots with the ability to manipulate small components accurately. Nevertheless, the main advantage of robotics remains their reprogrammability. As the product changes, the manipulating equipment only requires a change to the controlling program. Thus, robots provide a key step in flexible automation of a wide range of operations in many sectors.

Robots have so far found application in four main areas:

(a) Manipulation, across many sectors and tasks;

(b) Operations, including paint spraying, glueing, fettling and grinding, predominantly in the engineering industry;

(c) Assembly, including electronic and mechanical components and also extending to heavier duty work such as welding;

(d) Test and inspection, again in several sectors.

Despite the breadth of potential application, in recent years the diffusion of robotics has slowed. This reflects the problems in providing robots with sufficient sensitivity to reproduce many manual operations, especially those that depend on sight or touch. Developments are leading to the emergence of what are termed "second generation" robots possessing more than rudimentary sensory systems. These are likely to begin to diffuse widely, especially in assembly automation.

3. Computer-Aided Production Management (CAPM)

This is a generic name for a range of computer software supporting production management activities such as inventory control, production planning and control and purchasing. Most CAPM systems are based on some form of Material Requirements Planning (MRP) and recent versions extend this to Manufacturing Resources Planning (MRP2), which takes data from sales forecasts and customer orders to generate a Master Production Schedule (MPS). It then uses this to calculate material requirements (and hence purchase and works orders) and capacity requirements so as to make optimum use of the plant available.

MRP is a way of ensuring the availability of finished products to meet orders, and of the necessary components for their manufacture. It is a simple concept but the practical difficulties of fulfilling order variations without carrying excessively high and expensive inventories makes it highly complex to realize in practice. (There are variations, for example, in customer demand over time, in costs, in uncertainties in manufacturing capacity for components made in-house and in shortages or delays in delivery of bought-in items.) Without the use of computers, only very superficial and infrequent MRP can be carried out.

In a computer-based MRP system, the computer makes a link between information about production, purchasing and marketing. It provides management with a tool for identifying priorities in purchasing and production, for optimizing the use of capacity and for integrating supply and demand. In the longer-term it offers ways of improving sales forecasts, thus reducing the inventory levels needed by the firm and improving the purchasing function.

A typical MRP system and its operation is illustrated in Figures VII and VIII.

Figure VII. Simple Material Requirements Planning (MRP) system

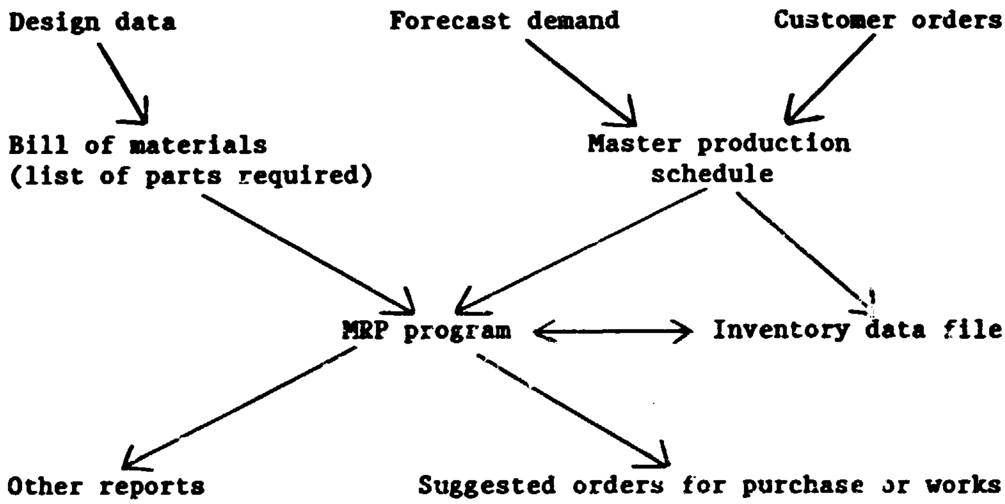


Figure VIII. Simple MRP process in operation

Master schedule: changes since last run collated

↓

Determine requirements to supply number of finished units of production required

↓

Explosion through the different levels of product structure in the bill of materials

↓

Determine overall material requirements

↓

Net these quantities against stock and outstanding purchase orders

↓

Calculate the bought-out and in-house orders split

↓

Calculate the order data (date due in production minus delivery lead time)

↓

Issue suggested orders

↓

Generate other reports

The planning process begins with a forecast of what the company expects to sell during a given period. This is converted into a production plan setting out what will be made and what the implications of this will be for the various production resources. The outcome of this process of breaking down the plan into resource requirements is known as the Master Production Schedule (MPS).

With pre-MRP systems, the MPS was then used to calculate what components would be required and this information was compared with what was held in stock to identify what needed to be bought. The problem with a system of this kind is that every time the MPS is recalculated, major changes in the ordering patterns for bought-in or made-in-house components would be involved. With a computer-based system it is possible to reduce fluctuations of this kind.

The next stage of the system is to use the MPS to generate a detailed Material Requirements Plan setting out in detail what needs to be bought-in, made in-house, etc. Most systems then incorporate a Capacity Planning function, which allows the system to optimize the use of existing manufacturing capacity and to warn management of any overload problems so that adjustments to the actual production plan can be made. The major advantage of such a system is that it can be run at frequent intervals, thus minimizing the uncertainties involved and providing much more accurate control over the entire process. As a result, manufacturing resources are conserved and inventory levels are kept as low as possible.

By extending the role of MRP beyond simply automating the stock control area to cover a process optimizing the use of production resources and the link between production and the rest of the business, the system becomes a much more powerful aid to management. The philosophy behind this approach (often called Manufacturing Resources Planning or MRP2) - essentially involving closing the loop between supply and demand - is illustrated in Figure IX.

Figure IX. Closing the loop in Manufacturing Resources Planning (MRP2)

```
P   Business planning  <------------------------------- I ^
                                                          I I
L   Sales planning  <---------------------------------- I I
                                                          I I
A   Production planning  <----------------------------- I I
                                                          I I
N   Check resources:  round cut capacity plan           I I
       (if not OK, repeat above cycle)  -------------->   I
                                                          I
N   Master Production Schedule  <---------------------- I I
                                                          I I
I   Material Requirements Plan  <---------------------- I I
                                                          I I
N   Capacity requirements plan  <---------------------- I I
                                                          I I
G   Check planning:                                     I I
       (if not OK, repeat above cycle)  -------------> I I
-----------------------------------------------------------I
                                                          I I
E   Purchasing of materials  ------------------------> I I
                                                          I I
X   Shop-floor control  -----------------------------> I I
                                                          I I
E   Performance measurements  -----------------------> I I
                                                          I I
C   Feedback information to operational                 I I
       and strategic planning level  ----------------->   I

U

T

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```

Although such systems appear logical and relatively simple in concept, there have been significant problems in their use since the 1960s when basic MRP systems were first introduced. Early systems suffered from a number of problems which had more to do with organizational and human factors than technological.

Problems included:

(a) Poor quality data input (because of lack of commitment or even deliberate action); poor data in the system renders information generated ineffective or wrong;

(b) Poor implementation; many systems remained the province of data processing experts and were often imposed upon the rest of the organization;

(c) Lack of commitment from senior management;

(d) Slow in operation (runs could take several hours) and unresponsive to changes;

(e) Lack of feedback provision to take account of changes in capacity, order levels, lead times, etc;

(f) Often seen as the responsibility of one department - usually Data Processing (DP) or stock control - rather than an organization-wide one;

(g) Weak links to other aspects of the production process such as quality control.

As a result, MRP systems worked best for those firms with little basic variety in product range and with relatively stable patterns of orders and supply. More advanced systems, such as MRP2, were developed not only to maintain the basic principles but also to improve the practicalities. However, although many elements such as improved feedback and responsiveness to change are designed into the system, much still depends on the way it is implemented within the organizational context.

4. Advanced materials handling system

This can include a wide variety of transport and manipulation technologies including stacker cranes, pallet handling systems, "intelligent conveyors" and Automatic Guided Vehicles (AGVs). All these share the same element of programmability and are therefore, unlike earlier generations of mechanical materials handling systems, not configured for one product or process. In addition, the ability to control these individual elements by a host computer means that, for example a whole fleet of AGVs can be managed at the same time, opening up opportunities for managing materials flow as a complete system rather than as a set of discrete operations. In turn this transport system can be linked into the production scheduling or other computer systems, making it possible to optimize the flow of materials through the plant.

5. Automated warehousing systems

Although one of the main trends in advanced manufacturing is operation with minimal stock levels in both raw materials and work-in-progress, this rarely means totally stockless production. Some form of storage of incoming materials and partly-processed goods will often be required. In this area, programmability has made considerable improvements on the way material is stored and retrieved through the use of automated warehousing techniques. Such systems have two key features. First, they allow for computer "mapping" of physical storage, so that every storage location is held in the computer memory. This means that at any time, the stock controller knows exactly where an item is in the stores, thus cutting down the search time. Second, the storage/retrieval mechanisms can themselves be automated - by pallet cranes, picker robots, or other devices that are capable of moving to the storage location, collecting (or inserting) items of stock and interfacing with the transport system. This again speeds up the process of materials management.

Once again, the advantages are considerably increased by the linking in of such computer-controlled systems with other parts of the operation such as the transport and production planning and scheduling system. In this way, items spend the minimum time necessary in the stores and the maximum time being worked upon - helping to keep inventory levels (and hence working capital tied up) to a minimum.

6. Flexible Manufacturing Systems (FMS)

This is a term given primarily to integrated automation of machining and handling operations in the metalworking and associated fields. In most Flexible Manufacturing Systems, combinations of computer controlled machine tools are loaded/unloaded and material is transported by automated systems under overall computer control. The system is also scheduled by computer so that optimum use can be made of the machinery and small batches produced economically (4).

The principles of flexible manufacturing are, of course, applicable to a much wider range of sectors. In any application where set-up times are significant, programmable automation can be used to reduce these and thus provide greater flexibility.

Examples include:

(a) Food processing, where a standard microprocessor controller can be used to sequence the weighing, mixing and processing of a variety of different recipes within the same broad product range. In one UK manufacturer of dried soups, a standard microprocessor-based system was used to provide up to 200 different recipes and 30 different mix cycles on the same basic plant. At any time, up to 24 of these recipes could be in production in the plant; in addition, the system automatically adjusts both the washing/cleaning cycle and the energy balance.

(b) Textile manufacture, where a small firm making a range of narrow-fabric woven labels successfully developed its own microprocessor-based system for weaving name tapes. These labels (used to identify children's clothes at school) are always only required in small batches, usually around 24. The flexibility required is considerable since the traditional way of making these labels would be to punch a different set of Jacquard loom cards for each and stop and reload the loom between batches. Using the microprocessor system has allowed the firm to provide rapid delivery and high quality customer service on this product range even during the high season, just before the new school term when a high volume of orders come in. In addition, several new label styles and designs have also been introduced, which can also be made on the same equipment by changing the control programmes - allowing the firm access to new markets.

Once again, the advantages of increased flexibility within one operational area can be considerably enhanced if the system is linked into a wider network - for example, with materials management, production scheduling or product design.

7. Automated test equipment

With the implied increases in speed of production arising from many of the above systems, and with the growing emphasis on quality comes a need to improve the speed, reliability and accuracy of the testing and inspection process. Various systems exist providing high speed electronic testing of different parameters. Once again, a key advantage of these is that they are not dedicated to a particular product but can be adapted by changing the control programs covering the test sequences, desired values, etc. In some cases - such as in the electronics industry - there is close synergy between product design and testing so that the test routines are generated at the CAD stage.

In other cases, particularly in the engineering industry, there is a move towards testing and inspection in-process rather than at a quality control station near the end of the process. This has the major advantage that faults or errors can be detected early and scrap-rework levels reduced. Here a range of equipment - such as Co-ordinate Measuring Machinery (CMM) - is available, combining high accuracy and speed of measurement with the ability to feed back control information not only to the quality management function but also to the control computers managing the production machinery. So, for example, if a CMM picks up that a component is beginning to move out of tolerance, it is possible to identify the machine tool responsible and to make corrections to its control program to compensate. Once again, the speed and accuracy of such an integrated system means that minimum scrap is made and process interruptions are also reduced.

Systems are also increasingly emerging for monitoring process equipment as well as product parameters. These include tool wear sensors for machine tools (which again have an automatic compensation capability, reducing the incidence of interruption due to broken tools) and temperature monitors for injection moulding equipment.

8. Factory automation networks

In order to connect the various elements together into an integrated system, some form of communication network is required. The configuration of such a network will vary depending on the amount of equipment to be linked and the likely amount of data traffic that will flow along it; but in general, the pattern will require some form of what is termed a Local Area Network (LAN). In its simplest form, this can be a pair of wires running between each item of equipment. Alternative requirements may call for a more complex high speed and high capacity network (such as fibre optic cable) incorporating sophisticated computer control. A number of proprietary LANs are available (such as Ethernet), which are suitable for integrated manufacturing cells, but there is a need for more advanced networks (and standardization of software protocols, to be discussed later) to support full-scale CIM.

Two strong contenders for the role of de facto standards for such networks are the Manufacturing Automation Protocol (MAP), developed by General Motors for connecting items of IT-based production equipment, and the Technical and Office Protocol (TOP), developed by Boeing for design and office-related IT interconnection.

9. Expert systems

Considerable research has also gone into providing factory automation projects with a degree of "artificial intelligence". Here, emphasis has been placed on so-called "expert systems", in which knowledge and experience normally forming human expert judgement can be embodied into computer systems. These systems are able to provide a significant measure of decision support and to learn from their experience, improving the quality of advice over time.

Examples of expert systems that are beginning to be used in practical ways (as opposed to development trials) include those for project management of large and complex projects and for configuring complex computer systems to suit particular customer requirements.

Other examples include:

(a) In the Lockheed Missiles and Space Corporation, around 55,000 instruments need to be calibrated each year. The firm is now using expert systems techniques to mimic many of the basic technician activities, thus reducing the time and cost of the process.

(b) The General Electric Company has developed an expert system for the plastics injection moulding industry incorporating a knowledge base derived from some of the world's leading plastics technologists. The system allows moulders to obtain the best performance from their plant and to diagnose quickly the likely causes of error when batches move off quality limits.

(c) The Renault car company of France is using expert system techniques to assist its 9,000 dealers in diagnosing car repair and service problems.

(d) Several major computer manufacturers - notably Fujitsu and Nixdorf - are using expert systems to improve diagnosis and fault-finding.

B. Proliferation of choice

The range of choices available in these areas is growing. For each component technology there has been a massive expansion in what is available to suit different needs. Although the pressures for change are increasingly common to all manufacturing plants, their particular requirements will, of course, vary widely. Small firms making small batches of high value components will differ radically from those making high volumes at low margins. This diversity is reflected in the technology supply side trends.

In the late 1970s, there were single, high cost systems for FMS, CAD, etc., which were only acccessible to a small population of large firms. Suppliers have since moved towards a much wider and rapidly proliferating set of choices to suit different firm sizes and budgets. This range expansion can be seen in all fields of Advanced Manufacturing Technology, especially with the emergence of the PC as a low-cost standard computer on which software development efforts could be focused. Significantly, it is in the smaller cheaper system field where the major market growth has taken place.

The following examples illustrate this:

(a) In CAD, the dominance of a small number of turnkey suppliers in the 1970s (Computervision, Applicon, Calma, etc.) based on mini-computer systems and multiple workstations has given way to an explosion of choice from around 250 different suppliers with costs ranging from £5,000 to £50,000. Such systems use hardware ranging from a single PC to multi-user systems and offer options ranging from simple wire frame 2-D draughting capability to full 3-D solid modelling, surface modelling, dynamic simulation, etc. (5). Table 3 shows the growth in options.

Table 3. Growth in options for CAD

1960	1970	1980
US-based, mainly experimental	Europe and US	World-wide
Mainframe based	Mini-computer based	PC-based and high power 32-bit workstations; 2-D, 2.5-D, 3-D, 3-D+ and many features - solid and surface modelling, FE analysis, etc.
	10-20 suppliers of turnkey packages	Over 300 suppliers
Limited application, e.g. SKETCHPAD	Wide application in electronics, aerospace mechanical engineering and cartography	Very wide user base in most industries, although fewer using full multi-user turnkey systems offering 3-D and enhancements

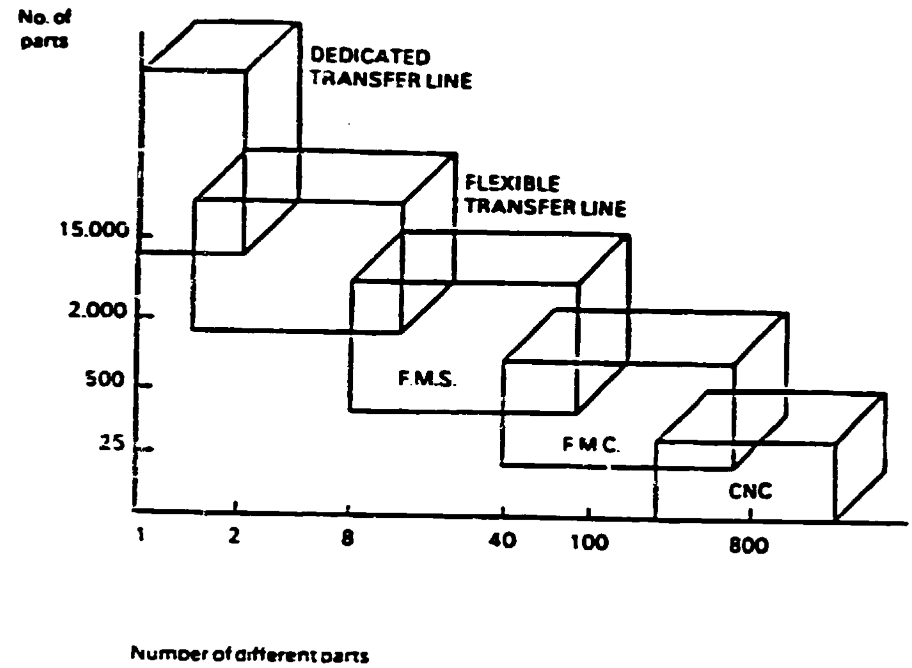
(b) Initially in CAPM, the single, high cost mainframe packages for MRP and related production management work (such as IBM's COPICS) were sold by the main computer builders and a handful of closely linked software houses. This pattern has given way to a modular approach with a range of choices: from simple PC-based implementations for activities such as stock control to fully integrated, large computer systems offering a wide range of modules that draw on a Master Production Schedule or Material Requirements Plan (see Table 4).

Table 4. Growth in options for CAPM

1960	1970	1980
Mainframe based, simple packages linked to data processing work	Mini and mainframe based, choice depending on scale of application	PC-based options plus mini and mainframe; Modular and integrated software packages
Only used by large firms	Growing use in inventory control MRP type systems and development of integration in software "suites" such as IBM COPICS	Multi-user systems and wide range of applications and users move away from DP department
High cost	High cost, application confined to medium/large firms	Low cost options

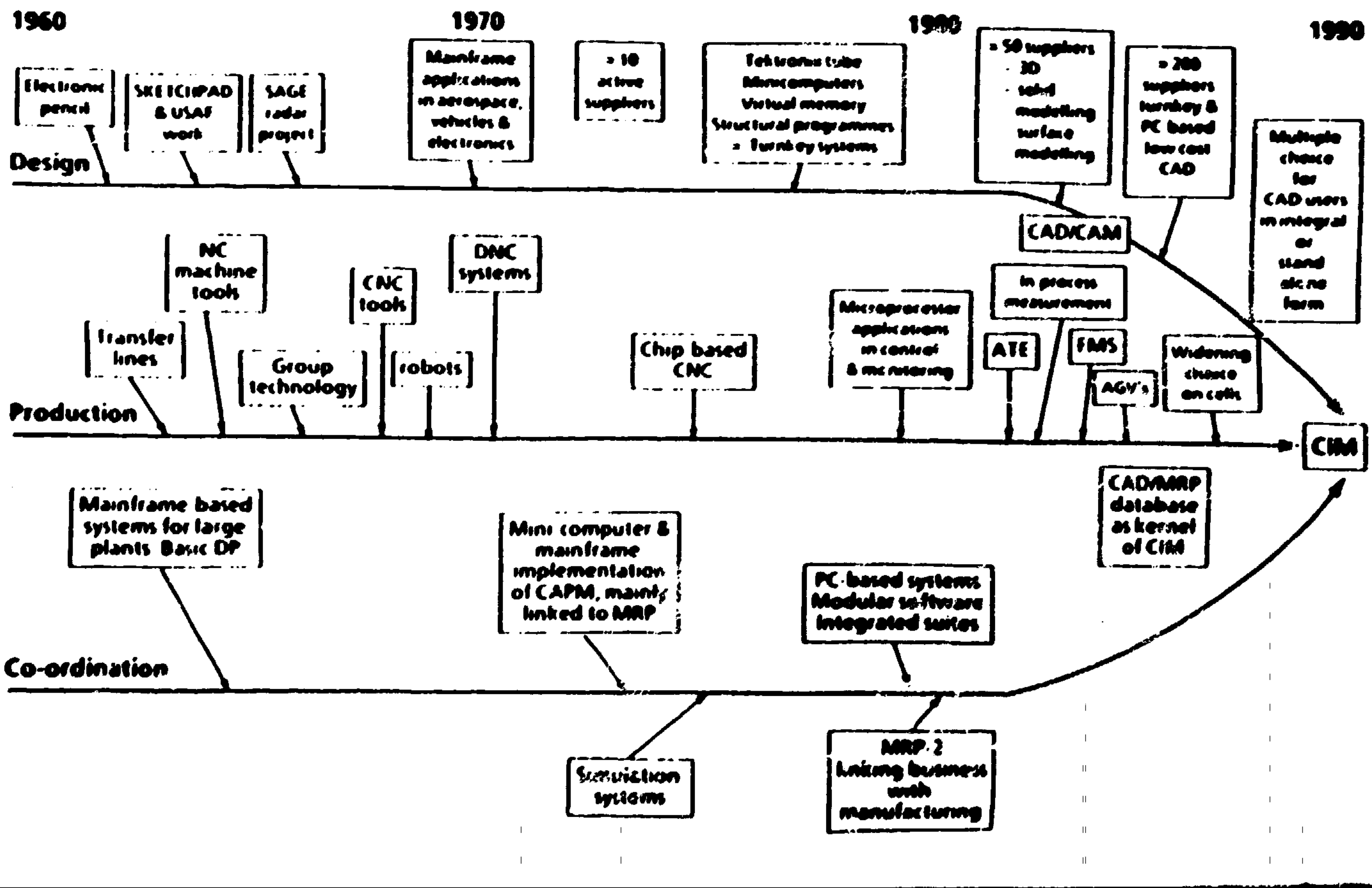
(c) In the case of FMS, the same pattern emerges. Whereas the first systems tended to be for large users (such as the aerospace industry), there is now a proliferation of choice among systems and configurations to suit different size firms, different budgets, different batch sizes, parts families and so on. This is not just an option on the small versus large firm axis; it also opens up the opportunity for firms to install flexible manufacturing cells within their larger pattern of production operations - as so-called "islands of automation". The range of choice can be plotted on the same volume/variety axes used earlier to effect a crude breakdown of manufacturing activities; from this it can be seen that there is, potentially, a flexible manufacturing configuration available for all classes of firms along that breakdown (see Figure X).

Figure X. Choices in flexible manufacturing



Similar patterns can be found in the field of robotics, microprocessor control systems and other fields (6). Figure XI summarizes these trends towards CIM.

Figure XI. Convergence of technological trends towards CIM



Notes

1. For a detailed discussion, see R. Kaplinsky, Computer-Aided Design (London, Frances Pinter, 1982.)

2. J. Bessant, "Computer-Aided Design in the Federal Republic of Germany", mimeo (UK, Centre for Business Research, Brighton Business School, 1987).

3. See K. Hoffman and H. Rush, Microelectronics and Clothing: The Impact of Technical Change on a Global Industry (New York, Praeger, 1988).

4. For a detailed discussion of FMS, see J. Bessant and W. Haywood, The Introduction of Flexible Manufacturing Systems as an Example of Computer-Integrated Manufacturing, Occasional Paper No. 1 (UK, Centre for Business Research, Brighton Business School, 1985).

5. J. Bessant, W. Haywood and H. Rush, Integrated Automation in Batch Production, Report to the OECD (Paris, December, 1986).

6. For examples, see J. Northcott and others, Microelectronics in Industry (London, Policy Studies Institute, 1986).

III. DIFFUSION OF COMPUTER-INTEGRATED MANUFACTURING

At first glance, the diffusion of advanced automation technology appears rapid, with market growth rates in particular sectors often in excess of 20 per cent per year. For example, a recently published consultants report for Europe suggests a threefold increase in sales by 1991 of industrial computer systems from their present level of around 22,000. Similarly, a 1987 report on the high technology factory automation market world-wide suggests a potential increase of 200 per cent by 1992 on current levels of spending, which in 1986 were around $18.5 billion.

Examples of individual component technologies also lend support to this picture:

(a) In the UK, one survey of computer use in the engineering industry (which uses a large statistically structured survey on an annual basis - 2,000 plus firms) shows growth in overall application of computer hardware and software rising at around 20 per cent per year (1).

(b) In CAD, the market was worth around $3.3 billion in 1986 and growth is expected to continue at between 15 and 20 per cent per year.

(c) In FMS, the number of systems world-wide is still growing at more than 20 per cent per year, and it is estimated that there are more than 1,000 systems in use (although there are problems in definition). It seems likely that the figures for smaller scale, stand-alone flexible manufacturing cells are in fact much higher.

(d) Industrial robotics has continued to grow, with total sales worth $1.88 billion in 1986; they are expected to rise to $2.18 billion by 1987 and $3.5 billion by 1990.

(e) The MRP market was estimated to be worth $300 million in 1986 and again expected to expand by between 15 per cent and 20 per cent.

Studies highlighting the use of these technologies in different sectors sugggest that penetration of such factory automation is growing. A recent three-country survey (2) suggested that more than 50 per cent of firms in manufacturing in France, the FRG and the UK were using some form of microelectronically-controlled equipment. In another recent survey based on 650 UK firms, this pattern of use is confirmed. For example, 58 per cent had CAD and 52 per cent MRP systems installed, with a further 44 per cent using master scheduling systems for production management (3).

These applications have taken place in all three spheres of manufacturing - design, production and co-ordination - but, as yet, there has been little inter-sphere automation, which would correspond to the higher levels of integration in our model.

Where this has taken place, it is usually in the form of an "island" of automation in a "sea" of conventional technology - for example, by installing a flexible manufaturing cell in a corner of a traditional engineering facility. Even greenfield site projects are only beginning to exploit higher levels of integrated automation although there is widespread agreement among commentators that this is the direction in which things will go.

The important point to note about this pattern of diffusion is that the majority of projects are still concerned with discrete applications and there is relatively little in the way of integrated automation. Indeed, the impressive growth rates for the above technologies should be placed in context; for many technologies there has been a substantial slowing down of market development.

For example, the CAD figures world-wide are much lower than in previous years; in the UK the figures for 1984/85 showed a 56 per cent increase, and in 1985/86 a still impressive 24 per cent. By contrast the 1986/87 figures are down to around 14 per cent. This drop can be largely explained by the shift towards more complex integrated systems with slower diffusion.

Similarly, growth in industrial robotics has also slowed, reflecting the limitations posed by current generations of technology. FMS diffusion has seen the most expansion in the smaller manufacturing cells end of the market, where these can be introduced as stand-alone islands of automation rather than as part of integrated systems.

Benefits of CIM

At first sight, the experience of early users of even partially integrated systems - islands of CIM - appear to confirm the promise of substantial benefits.

Consider the following examples:

(a) In research on Flexible Manufacturing Systems (combining production and co-ordination spheres in the metalworking engineering sector), a study of more than 50 cases covering a wide size range highlighted major benefits for all users, as Table 5 indicates.

Table 5. Benefits of FMS use by company size

Size of firm (no. of employees)	Lead time	Work-in-progress (WIP)	Machine utilization
	(Percentage)		
1-500	-66	-66	+45
501-1,000	-76	-63	+50
1,000+	-86	-70	+55
Average	-74	-68	+52

(b) In the Rolls-Royce Advanced Integrated Manufacturing System (AIMS) project for the manufacture of turbine blades, benefits included a reduction in lead time from 26 weeks to 6, a reduction in overall inventory of £4.6 million and an increase in labour productivity. The whole system cost £4 million and was paid for out of the inventory savings achieved in the first year of operation.

(c) One large manufacturer of men's shirts in the United States reported total savings of more than $10 million in seven years as a result of introducing CAD/CAM for grading, marking and cutting. Nearly a third of these savings came from a reduction in direct labour, another third was a result of the increased utilization of piece goods and the remaining third came from a combination of reductions in indirect labour, transportation, idle space utilization and various supply items. In general, it was found that firms in the clothing industry that had introduced CAD/CAM experienced between 25 and 40 per cent direct labour reduction, 1-2 per cent savings on fabric, 90 per cent reduction in training time and throughput savings of 50 per cent. Significant downstream savings in assembly time were also reported as a result of more accurate cutting (4).

It is also important to recognize that other benefits accrue from investments in AMT which may be intangible but which still make an important contribution to competitiveness. For one user of a large integrated system, these included:

(a) Improved control and reduced disruption upstream and downstream of the FMS;

(b) Ability to react quickly to required modifications or product changes;

(c) Ability to handle pre-production (R and D) batches under production conditions;

(d) Improved control over materials handling;

(e) Improved company image;

(f) Enabled introduction of multi-skilled working.

However, a number of problems make these benefits difficult to achieve and their incidence rises with the level of integration attempted. As has been seen, this pushes firms towards strategies looking towards investments in discrete rather than integrated systems, at least in the short-term. A recent report for the British Institute of Management makes the point that although firms have made investments in AMT, these have not always been successful (5). In one sample of 64 plants that had invested in some form of FMS, more than two-thirds had so far only achieved low payback, while others using CAD also felt that they were not getting the best out of them. Table 6 presents some of the data from this study.

Table 6. Payoffs from Advanced Manufacturing Technology (Base: 250 firms)

Technology	Zero to low payoff	Moderate to high
	(percentage)	
CAD	46	54
CAM	46	54
MRP	19	81
FMS	67	33
Robots	76	24

Sour(British Institute of Management, Cranfield, 1986.

Inevitably, this has led firms to revise their investment intentions downwards and away from the more complex systems technologies. Too much should not be read into figures of this kind, but they do demonstrate that moving to integrated configurations of technology raises a number of questions. Despite optimistic market forecasts and the promise of considerable benefits, a growing mood of caution is clearly developing among potential users. This emerges in the apparent slowdown in investment, in comments in the trade press and in a growing cynicism about much of the supply industry. It reflects, above all, a disenchantment with AMT's ability to deliver the benefits promised. There are several examples of costly failures and of systems working at a fraction of their true potential.

Although firms would rather not publicize their failures, it is instructive to consider them since they confirm the view that realizing the potential benefits offered by advanced automation is not always a simple matter of making the decision to invest.

Examples of major projects gone wrong are:

(a) The GM Saturn project, where performance expectations have been dramatically revised downwards despite massive investment in technologies and the acquisition of a key systems house to provide the necessary software support;

(b) The Computer-Aided Production Management facilities of the bicycle manufacturer TI-Raleigh, where the changes in computer control systems not only failed to produce improvements but caused a serious loss of production efficiency (6).

Even where systems do work, it may take several years to learn to use them well enough to exploit the sort of gains the suppliers suggested were possible. For example, in research on CAD, it was found that it took firms an average of two years to achieve "best practice" productivity gains (7). In another study on 44 robotics projects, half were abandoned before completion (8). A study of CAPM in the UK pointed out that "even advanced CAPM users have difficulty in understanding how best to use the numerous CAPM control variables (especially in combination) ... thus, they are not getting full benefit from CAPM systems" (9).

These appear to be symptoms of a negative reaction to the massive injection of AMT, which was supposed to make the manufacturing "patient" better. One of the most significant points now beginning to emerge is that technology alone will not solve many of the fundamental problems present in factories. It is argued strongly that there is no point in putting in sophisticated computer-based systems into factories that still operate inefficiently. As one interviewee on CAPM put it, "When you put a computer into a chaotic factory the only thing you get is computerized chaos!"

To add to this criticism, the evidence from those firms that have implemented organizational innovations such as Just-in-Time has been that they not only improve performance in areas like inventory reduction and quality management but they also help reorganize and simplify the overall operation. Careful analysis of the root problems and the key areas for improvement have shifted attention away from traditional targets like direct labour costs towards materials management and overhead reduction. It is argued - by users and consultants alike - that on the back of such simplification and organizational improvement, advanced technology stands a much better chance of succeeding.

An illustration of this can be found in the experience of the Digital Equipment Corporation in implementing a major CIM facility in Clonmel, Ireland. Although this was planned as a technological innovation and, five years on, is generally regarded as having made a significant contribution to improved performance at the plant across a range of indicators (such as productivity growth, stock turn, inventory reductions, lead time reductions and quality improvement), the plant director views the major benefits as having come from organizational learning. He identifies several key lessons which the company learned including the need to "simplify before automating. Most people who get into difficulties with investments that do not realize their potential do so because they try to automate their existing operations. Information technology and automation permit new and simpler ways of doing things" (10).

Notes

1. 1985, 1986, 1987 surveys of UK computers in engineering, Benchmark Research Ltd., on behalf of and reported in Engineering Computers magazine (Horton Kirby, Kent, UK, Findlay Publications).

2. See J. Northcott and others, Microelectronics in Industry (London, UK, Policy Studies Institute, 1986).

3. Industrial Computing (June 1987).

4. K. Hoffman and H. Rush, Microelectronics and the Clothing Industry (New York, Praeger, 1988) (forthcoming).

5. C. New, Managing Manufacturing Operations in the UK (Cranfield, UK, British Institute of Management, 1986).

6. Technology magazine (5 October 1984).

7. P. Senker and E. Arnold, Designing the Future: The Skills Implications of Interactive CAD, Occasional Paper No. 9 (Watford, UK, Engineering Industry Training Board, 1982).

8. J. Fleck, "Employment implications of robots", T. Lupton, ed., Proceedings of First International Conference on Human Factors in Manufacturing (Kempston, UK, IFS Publications, 1985).

9. G. Waterlow and J. Monniot, The State of the Art of CAPM in the UK, Report to the ACME Directorate, Science and Engineering Research Council (Swindon, UK, 1986).

10. B. O'Malley, "Why Invest in CIM?", B. Hundy, ed., Proceedings of Automated Manufacturing Conference, Birmingham, May 1987 (Kempston, UK, IFS Publications, 1987).

IV. BARRIERS TO DIFFUSION

A number of factors militate against firms' successfully implementing Integrated Automation Technologies (IATs). They can be considered under four areas:

(a) Investment costs and justification;

(b) Technological problems;

(c) Lack of in-house skills and resources;

(d) Organizational factors.

A. Investment costs and justification

Although the costs of IATs are falling to the point where they are accessible to smaller firms, decisions about investments often exceeding £1 million cannot be taken lightly. In particular, they imply a number of changes from the traditional approach firms take to investment justification, especially the need to take a longer-term strategic view of teechnology within the context of the overall business.

Thus, issues dealing with the market impact (or opportunity cost, in the case of decisions against investing) of increased flexibility need to be added to the more traditional shop-floor concerns of faster speeds, greater reliability and labour-saving. For many firms, this involves a shift in the locus of responsibility for decision-making and planning for automation. What used to be a shop-floor activity, primarily the province of production engineers, now becomes a boardroom issue on which those responsible for strategic planning need to have a view. In turn, there is a need for information input to the decision process - from marketing, from product design, as well as from production.

The basis on which investment is justified and the techniques whereby the case is made are undergoing changes. Simple return on investment techniques are being replaced by complex alternatives that take account of the strategic issues and try to provide a quantitative rationale for decisions which up till now have often been taken largely as an act of faith. At the same time, the traditional criteria - for example, direct labour saving - are less easy to apply as integrated technologies often change the way the organization needs to utilize its assets.

B. Technological problems

Although there are problems in extending the range and capability of discrete items or equipment (such as CNC machining centres), the main issues concern integrating different elements. The difficulties are mostly in the software and in the overall integrating philosophies to be used. Physical integration of equipment (e.g. interfacing robots and handling devices to machine tools) is relatively straightforward, but software integration - the problem of getting different items of equipment to talk intelligibly to each other - is a major difficulty.

In essence, what is needed is some form of "highway code" for all the electronic traffic in an integrated automation system establishing clearly the various "rules of the road": who has priority, speed limits, parking areas, etc. This would be difficult enough if all the potential inputs of electronic traffic were part of a system made by the same manufacturer - but in practice, the requirement must be for an "open" system permitting any item of equipment from any supplier being linked into a factory network of any size. Such an Open System Interconnection (OSI) standard is crucial to successful software integration. Once established, producers of automation equipment can design their products accordingly, suppliers of components to them can build special translator chips - and the whole market has a chance of standardizing.

The fear is, of course, that a single supplier will be able to impose particular standards and "lock in" users to certain equipment; thus, there is concern and argument about which standard to adopt. Specifications for OSI have been agreed at the International Standards Organization in Geneva and a proposed seven-layer model has been available since 1978 in outline form. This will allow the kinds of interconnection needed in a factory from basic automation rights up to high levels of integration at plant level and beyond.

Having a specification for OSI is not sufficient, however, since that was established primarily for general communications between items of IT. The requirement is for manufacturing a specific version and the front runner for this is the General Motors Manufacturing Automation Protocol (MAP). GM developed this in response to its own urgent need for standards. GM has between 20,000 and 30,000 programmable devices and ambitious plans for factory automation, which will depend crucially on being able to connect these together. Since no supplier was able to offer compatibility, GM has developed its own protocol to which it requires suppliers to conform.

MAP is not a GM product but a standard specification which suppliers have largely begun to adopt. Most major automation manufacturers, including Fanuc of Japan, have announced that they will support MAP; semiconductor firms like Intel have also begun producing chips to enable them to implement it. The likelihood of MAP becoming a de facto standard appears high as a result of this and also because of backing from other agencies (1).

There are still some doubts about the full success of MAP. Recent announcements by the Digital Equipment Corporation, for example, have been highly critical of the approach and a number of UK firms are worried that later versions of the protocol may not meet their particular requirements. Other options also exist - for example, alternative protocols such as IBM's System Network Architecture which has the advantage of being well-proven in practice but worries many users because of the possible resulting "lock-in" to IBM, or software integration based on "portable" language like UNIX or other "home-grown" attempts at integration. Furthermore, for many tasks, simpler networks with established protocols can be used. For example, many factories are already running networks under Ethernet.

Nevertheless, there is general agreement that standards based on OSI principles will emerge. In addition to MAP, there is also the Technical Office Protocol developed by Boeing. TOP is aimed at design and office activities and includes a number of attempts to formalize the exchange of graphics information between CAD systems - for example, between firms supplying and buying components in the vehicle industry. This has important implications for any supplier of automation services since it will need to become and remain conversant with the nature and development of such standards.

C. Lack of in-house skills and resources

Integrated automated systems require skilled resources in two key areas: to support the implementation project and to support the long-term operation of the system. For the latter, there are already serious problems of resource shortages at the level of technician and above.

The pattern of convergence observed in the technology is thus reflected in the type of human resources required to support integrated manufacturing systems. Although the level of direct labour needed to support CIM is falling, its composition reflects a growing need for breadth and depth in skills and experience. As systems are becoming more physically integrated, bringing a number of discrete operations into a single complex cell - not only is there a considerable shift in the balance of direct to indirect workers, but those direct operators who remain also become responsible for a much more complex and concentrated system.

Multiple skills are an important requirement, bringing together different engineering disciplines (e.g. hardware/software, electronics with applications, manufacturing systems engineering and different craft skills (e.g. maintenance). With the decreasing importance and involvement of direct workers, those who remain need to be flexible and highly trained in first-line maintenance, diagnostics, etc. The increasing number of indirect support staff must be broadly skilled and able to respond to a wide variety of problems right across an integrated facility.

As the overall numbers of direct operators decline, the decision about how to train and use those who remain grows in importance. Here there is growing debate about whether traditional patterns of work organization based on the ideas of Taylor and Ford are necessarily appropriate in the case of integrated systems. Attempts to develop a fully automatic factory - that is, one with no human intervention whatsoever - are unlikely to meet with much success because of the enormous risks and costs associated with developing suitable software to control such systems. As one researcher from the Federal Republic of Germany puts it, "Most managers and production planners follow a strategy to replace human work still further by enforced use of computers on the shop-floor and in the technical office in an integrated manner. Since this strategy is in danger of creating new problems, the growing minority seeks to avoid them by reorganizing production and rearranging the division of functions between man and machine in a way that makes use of the workers' skills instead of reducing them to operating servants" (2).

Research in the UK for example, has begun to demonstrate the importance of rethinking operator roles within advanced manufacturing systems (3). In work on small flexible cells (which was based on an analysis of the causes of system downtime), researchers found that in addition to a deskilled machine-minding role, there was a need for a highly skilled "operator midwife" role which involved intervening when problems with the largely automated control system emerged. The objective in such systems moves from one that sees labour as a necessary evil and a cost item, to be reduced or eliminated wherever possible, to one that regards labour as an important aid in keeping the utilization of the system high - and thus in recovering its high capital costs.

With increasing dependence on indirect workers to keep such systems running - for example, in the field of maintenance - comes a need to examine the pattern of skills availability and its development. Technological integration is bringing a number of new demands in the skills required of an individual, particularly in the areas of more flexibility and breadth.

Empirical studies identify this requirement in a number of industries - for example, the degree to which provision or lack of suitable skills and training can affect the speed of firms in achieving best practice performance with CAD systems (4).

In the Federal Republic of Germany, a detailed study of the large FMS installed at Messerschmidt-Bolkow-Blum in Augsburg points out the extent to which maintenance skills (especially the newer ones such as systems analysis and diagnostics) contribute to the utilization of advanced manufacturing systems - and to the rapid repayment of their initial costs. Analysis of more than 6,000 hours of operation revealed that more than half the system downtime was due to unscheduled stoppages or breakdowns. Of the time taken to repair and bring the system back into operation, around half was taken up in diagnosis. The conclusion was that "the more complex and automated the systems were, the higher the skills level of the maintenance specialists had to be to achieve reasonable failure rates and implement facility improvements ... and ... the lower the personnel levels were (producing with automated facilities), the broader the educational background of these workers (operators and maintenance) had to be" (5).

As firm size decreases and the level of experience in implementing major strategic projects also declines, the need for outsiders to become involved increases. Although a production engineer may be able to manage the introduction of a new machine tool, the scale of integrated systems in, for example, an FMS, means a number of new and important skills need to be brought to bear. At the very least a project team drawn from internal resources needs to be set up to oversee what may well be a three-year process. Such a team requires representatives from many different disciplinary areas. The degree to which control over day-to-day project management remains within the firm depends primarily on firm size and local resources (6).

Even when firms have the necessary project resources in-house, the configuration of systems requires close co-operation with suppliers of the various elements: hardware, software, handling systems, etc. The requirement here is to marry the in-house experience of the process to be automated with the specialist expertise from the supplier side. The further up the integration ladder projects go, the less likely an in-house implementation team will suffice; the model will shift to the pattern often found in the process industries with either a joint team or else a managing agent/contractor undertaking to provide a turnkey service.

D. <u>Organizational factors</u>

This last group of factors is also the most complex to try and evaluate. It is generally accepted that technological change requires some degree of organization in order to work successfully. Put another way, innovation theory stresses that "compatibility" - the degree to which an innovation fits into the context in which it is being placed - is an important determinant of adoption success. In the case of FMS and other integrated systems automation, this is particularly true and many commentators have talked about the need for a "new way of thinking" (7).

Underlining this point is the comment of many studies that the bulk of benefits come not from the technology but from the organizational changes firms were forced to make around the introduction of the technology. In the extreme case, firms that looked at FMS and other systems as a means to obtain benefits such as reduced inventories, shorter lead times and higher quality find that their feasibility studies highlight areas of potential organizational as well as technological change. Once the organizational changes are implemented, firms may find that they no longer need complex integrated systems like FMS.

The elements of such organizational innovation and adaptation vary with each firm but typically include:

(a) Functional integration. This is becoming a key feature in Computer-Integrated Manufacturing. As technology brings different areas of the firm together, it becomes important to ensure that the problems of interdepartmental boundaries are minimized. In some cases this may lead to the creation of new roles or groups, either on a temporary (task force, project team) or a permanent basis. For example, there is the need - itself facilitated by moves towards CAD/CAM linkages within firms - for the design and production departments to work closely together to develop products suitable for manufacture on integrated systems. Such a "design for manufacture" philosophy is particularly significant in the flexible assembly automation field, for example, where small modifications to the design of an item can eliminate the need for complex manipulation or operations within an automated system. In one notable case, redesign of the product led to a reduction in the number of operations (handling and machining) from 47 to 15 - with significant implications for cost and lead time savings. As one manager involved put it, "FMS is going to drive the shop - but it's also going to drive the people who design the product and the production engineering ... those parts have got to be made on this investment if we are to justify it".

The essence of such functional integration is not to eliminate specialist skills but to bring them to bear in a co-ordinated fashion on the problems of designing, producing and selling products. The intention is to create a single-system view of the process rather than one with many parochial boundaries and little interchange across them.

(b) Vertical integration, with shorter and flatter hierarchies and devolution of decision-making. In the same way as integrating technologies require closer functional integration, so they imply shorter hierarchies and greater vertical integration in the organizational structure. In order to exploit the full benefits of a rapidly responsive and flexible system, it may be necessary to create a managerial decision-making structure that is closely involved with the shop-floor and has a high degree of delegated autonomy. One approach being taken is setting up semi-autonomous business units, concentrating not only the necessary production facilities and support associated with a particular product family, but also the relevant business and financial functions. In turn this has implications for the training and qualifications of those involved in such units. Since these personnel are effectively members of a small company setup within the framework of a larger one, the range of responsibilities they undertake is much broader than that of functional specialists.

(c) Work organization. At the level of the shop-floor, considerable changes are implied for the pattern of work organization. With greater reliance on a small group of workers and managers comes the need to look for models of production organization that move away from task fragmentation, division of labour and control by external regulatory systems of sanctions and rewards. Instead, there is a need to evolve alternatives based on small autonomous working groups, with high flexibility and internal control. There appears to be growing recognition of the inappropriateness of approaches developed by Taylor and Ford, which are based on a fundamental dis-integration of work for activities surrounding a fundamentally integrating set of technologies.

(d) Strategic integration, matching manufacturing investment strategy with the wider business objectives of the firm. Traditionally, strategy has been about deciding which products to make for which markets. The concept of a manufacturing or technology strategy relating these to the manufacturing field is relatively new and is much needed. In many cases, firms are implementing integrated technologies without a clear idea of their fit with a broader strategy. Too often such systems are installed with little in the way of strategic objectives or criteria to measure success in meeting these. Where criteria do exist, they are often defined in a narrow technical or financial sense rather than taking into account the wider context of the effect that technology might have on the business environment. For example, an FMS might be judged on narrow criteria within the production sphere - throughputs, speeds, labour-savings, etc. - rather than by other strategic benefits which may (or may not) ensue, such as improved competitiveness as a result of shorter lead times and greater agility in the marketplace (8).

(e) Cultural integration. A general point about adaptation within the firm concerns the idea of organization culture - the set of beliefs and norms about "the way things are and the way we do things around here". The challenges posed by integrating technologies will require new ways of thinking about how to organize to make best use of the technologies. But the organizational ability to exploit the technologies successfully will depend on how far the prevailing culture is open to change. Traditionally, production has been characterized by a culture that emphasizes things like stability, bureaucratic procedure (as in "doing things by the book"), specialization and division of responsibility and so on (9). Although such a culture was traditionally well-suited to the demands of production in a stable environment, it is less so in one characterized by fluctuating demands in the marketplace where agility and responsiveness and flexibility are the key factors associated with success. Consequently, there is a need to develop ways of moving towards a more open and flexible culture in production - and this may again have implications for structures, methods and processes within the firm.

(f) Inter-firm links. Parallel with these organizational developments within firms has come the gradual realization that the manufacturing process consists of a series of firms and links. Increasingly, the relationships between firms are being recognized as important as the firms themselves in terms of controlling costs and adding value.

Technological process innovation and investment cannot, therefore, be considered solely in the context of individual firms. Rather, strategies must be developed taking into account the material and component suppliers and the distribution system.

For example, in the UK automotive and electronics industries, there are clear signs of consultation between component suppliers and their customers on investment in CAD. In order for such steps to have been taken, the relationship between the two parties must have developed from the traditional model, often based on conflict, to a "resolved" model that relies upon a "common sense" trust and concern for mutual development (10).

Notes

1. For example, the UK Department of Trade and Industry sponsored a major awareness raising event (CIMAP) at the National Exhibition Centre in 1986 and established a Centre for Conformance Testing to support the use of MAP.

2. P. Brodner, "Skill-based production - the superior concept", H.-J. Bullinger and H. Warnecke, eds., Towards the Factory of the Future, Fraunhofer-IAO (Stuttgart, Springer Verlag, 1985).

3. T. Wall and others, presentation made at Manpower Services Commission Workshop, Aston University, March 1986.

4. P. Senker and E. Arnold, Designing the Future, Occasional Paper No. 9 (Watford, UK, Engineering Industry Training Board, 1982).

5. G. Handke, "Design and use of flexible manufacturing systems", K. Rathmill, ed., Proceedings of 2nd International Conference on Flexible Manufacturing Systems (Kempston, UK, IFS Publications, 1982).

6. It is worth putting this into perspective; the planning for many FMS systems can represent a significant proportion of the total costs. In the Mino Kama facility for Yamazaki in Japan, around 100,000 man-hours of planning were required for the 18-machine FMS.

7. P. Dempsey, "New corporate perspectives in FMS", K. Rathmill, ed., Proceedings of 2nd International Conference on Flexible Manufacturing Systems (Kempston, UK, IFS Publications, 1982).

8. C. Voss, "A manufacturing strategy perspective", C. Voss, ed., Managing Advanced Manufacturing Technology (Kempston, UK, IFS Publications, 1986).

9. This is an example of what Burns and Stalker, The Management of Innovation (Tavistock, UK, 1961), call a "mechanistic organization".

10. R. Lamming, "For better or for worse? Technical change and buyer-supplier relationships in the UK automotive component industry", C. Voss, ed., Managing Advanced Manufacturing Technology (Kempston, UK, IFS Publications, 1986).

V. SUPPLIERS OF TECHNOLOGY

From the review of problem areas in previous sections, it is clear that users contemplating the implementation of advanced and integrated manufacturing systems are likely to need varying degrees of support in the process.

For a few large firms with experience in automation and complex products, the main resources to support development of complex systems can be found in-house. The principal external resources needed are equipment (and even here the buyer firm is in a strong and well-informed position to specify exactly what is wanted and to evaluate different suppliers against this) and specialist expertise in narrow problem-specific areas.

At the other end of the scale, an inexperienced small or medium-sized user firm will need a wide range of support including:

(a) Technical support in business and technical audit, planning, simulation, etc., to arrive at a suitable configuration. This might include consideration of alternative solutions to the problems facing the firm such as the introduction of quality programmes or Just-in-Time;

(b) Help with financial and strategic planning;

(c) Feasibility study and investment justification support;

(d) Education and awareness raising, especially at board level;

(e) Support (perhaps via an external managing agent/project manager) for the implementation, planning and execution of a large-scale project. This latter job would include bringing in the different systems and suppliers, ensuring they deliver on time, and coping with emerging problems;

(f) Training for operation;

(g) Support for organizational development and necessary changes in management and execution.

The majority of firms fall somewhere in between the two categories just described. In one study on FMS in smaller firms (1), most had made use of one or more sources of external support, ranging from consultants at the planning and selection stage; through software houses to assist in systems integration; to computer and machinery suppliers to help during the implementation process. Most of these projects took three years or more from initial planning to final operation and the general experience was that projects on this scale are beyond the normal capacity of the firm to plan and manage completely alone.

Significantly, there were many criticisms of the various suppliers and consultants, especially of consultants (" ... telling us what we already know and costing us an arm and a leg as they do so!") and of computer suppliers ("All they want to do is shift boxes - they'd tell you anything in order to make a sale!").

Sources of support

As has been seen, moving into the implementation of integrated automation systems will often require a range of support complementing users' in-house resources and experience; few firms will be happy to leave the entire project to outsiders to plan and manage. Thus, some form of partnership involving joint problem-solving is to be preferred.

Components of problem-solving from the supply side would include:

(a) Aiming to provide solutions to problems, rather than technology packaged and sold as a panacea for all ills;

(b) Total rather than partial solutions (which often reflect supplier bias towards selling a particular product);

(c) Help in choosing different approaches to solving the problem - for example, involving managerial, organizational as well as technological change;

(d) Incremental approaches permitting gradual change which the organization can afford and, more important, can absorb;

(e) Guarantees of support and technical service in the long-term.

There are a number of different actors in the automation market but so far none are really in a position to supply this range of services and equipment. As one major supplier put it, in its own advertisement: " ... the main obstacle to integrated manufacturing is the inherent incompatibility between existing systems. Integration was not a consideration when many of these systems were acquired. There is no simple solution to the problem. CIM is a business strategy, not a single product you can buy. No single supplier has all the products to integrate a manufacturing enterprise" (2).

Although suppliers generally recognize their inability to offer turnkey solutions, there are still serious weaknesses in the way they are meeting user needs. For example, some suppliers claim to offer total solutions but provide weak or no support in some areas.

Users and suppliers are also responding by:

(a) Forming joint ventures or consortia;

(b) Using systems integrators/managing agents to put a package together on behalf of a client;

(c) Users reducing their needs to a level at which a single source can supply and guarantee a system. For example, the market growth in smaller flexible manufacturing cells rather than in large and complex systems is a reflection of this;

(d) User firms carrying out configuration and project management in-house on a "do-it-yourself" basis.

The supply side can be categorized into a number of different groups as follows:

1. Computer suppliers

These are firms whose main background is in computers but which have begun to diversify in a number of fields in recent years on the applications side. Although computers have been used in process control directly in the process industries for many years, their role in batch manufacturing has been primarily in data processing applications (such as payroll) and in production co-ordination such as Material Requirements Planning and Computer-Aided Process Planning (CAPP). Here new market possibilities are opening up in both new application areas (e.g. CAD, FMS, simulation and expert systems) and in networks and hierarchies of control which require central and distributed computer power. Some of these computer suppliers have had traditionally strong links with industrial process computers or control instrumentation; others have built up experience with microprocessor control systems which are much more widely used in manufacturing applications.

All the major computer suppliers offer CIM packages. These comprise computer hardware in a range of sizes and power, and software that is often of a modular nature designed to integrate into a complete suite with modules tailored for particular production management applications and networks. In larger firms such as IBM, diversification has gone further towards full factory automation supply capability, with recent acquisitions including CAD/CAM, robotics and factory automation networks.

As might be expected, many of these companies are themselves at the forefront of internal automation - often to an advanced level. Such investments have an important advantage in terms of learning by doing. Their experience can be used to improve the design of systems being sold and to sharpen the marketing approach because of greater understanding of the user side of things. Significantly, these companies have adopted a mixture of advanced technology (sophisticated computer networks and controls) and organizational innovation (such as quality programs, Just-in-Time scheduling, purchasing and manufacturing). As a result, they are becoming aware of the need to sell more than just technology if they are to provide customers with solutions to problems rather than simply computer systems.

The main weaknesses of suppliers on the computer side are that they are often seen to be "pushing boxes" without concern for longer-term concerns of users; that they are trying to "lock-in" customers to particular brands; and that they are not experienced in all areas now related to CIM and not always offering the most appropriate solution (e.g. offering high cost and complex MRP2 systems when simple Just-in-Time approaches might be more suitable). There is also a high degree of cynicism among potential users of computer systems who have found many of these problems in earlier generations of computers used in DP applications.

2. Software and systems houses

These are organizations primarily involved in developing software and designing systems, either on a freelance basis or as part of larger firms. These organizations have the advantage that they tend to be hardware supplier-independent (although some of their software is designed to run on particular machines) and they can configure semi-standard software to suit user needs. Several also offer new products specific to the emerging needs of systems planners and developers - such as simulation packages.

The growth in integrated systems has seen the expansion of this sector, often as the integration contractor in major CIM projects where software is seen as the key component. This has helped them enter the market as systems integrators and several are now offering a much broader range of services. The main weakness of software houses is, however, that many are still small operations and thus face problems in managing and implementing large-scale projects.

3. Equipment suppliers

A number of firms supply constituent equipment as components of CIM facilities including machines, handling systems, robots and control systems. Increasingly, they have extended their range to include handling systems (such as pallet systems or simple robots), tool management systems, etc. In some cases, e.g. CNC tools, the control systems are interchangeable so that customers can express a preference for what is, in many ways, a standard control box. This pattern means that certain kinds of systems can be offered on a turnkey package basis - for example, flexible manufacturing cells.

In other cases, e.g. on machinery for the food industry, the control systems may be much more specific. The trends are increasingly for such producers to offer more of a complete range of manufacturing systems and to negotiate licences or enter joint ventures in order to be able to do this.

The strength of this group of suppliers lies in their knowledge of their product and its traditional application areas in batch manufacturing. Where user firms have traditionally bought single machine tools, they may well look for the same supplier to implement more complex manufacturing systems for them. Their weaknesses are their relative inexperience in selling whole systems, in project management, in organizational innovations (such as Just-in-Time) and in other aspects which a smaller firm might need such as skills in the business side or long-term strategy. Many are learning by doing since their own product is made in small batches and to-order; many also run user education and awareness raising programmes as part of their overall marketing approach.

4. Management consultants

A number of the larger management consultancies have begun to offer some form of automation and factory management consultancy as part of their overall portfolio. Many of these manufacturing-related operations have been around for some time and were originally concerned with work study and other projects but have now moved to offer expertise in AMT.

Their strength is in strategy and consulting. They are used to helping clients diagnose the need for change in their organizations, helping them implement it and advising on strategic development. However, although some of these operations are growing - reflecting both the expansion of the market and the need for external advice - such consultancies are rarely able to provide the necessary resources themselves to design and build new facilities or to manage and commission large-scale projects.

Their role is becoming more important as user firms look towards alternative and complementary innovations in the organizational sphere - such as Just-in-Time and Total Quality Control - in addition to major technological changes. Such innovation is well-suited to consultancy since it requires skills in implementing organizational changes and is less resource intensive.

One other area of strength in the consultants' favour is their ability to arrange and manage some of the business aspects of AMT investment such as arranging financing and taking advantage of government support schemes. This ability to provide a broad support service is of value to the smaller firm - although, as mentioned, such breadth is not always matched by technological depth in actual implementation.

5. Engineering consultants

These have much in common with management consultancies, the main difference being that their technical and production management expertise base is much broader because they have concentrated on engineering and factory projects as their main activity. Some engineering consultants have performed such roles as in-house groups in larger organizations. Others are organizations such as industry-specific research associations with considerable sector-specific knowledge which they are now trying to market. Another important group involves those who originally entered the field selling microelectronics-related services and have now developed their skills and capabilities to address larger automation projects.

6. Systems integrators

This is a newly emerging group which aims at providing a measure of guarantee to potential users that the various pieces of technology and software chosen will actually fit and work together. The term "systems integrators" is beginning to be used widely to cover many of the other categories discussed earlier, but applies particularly to the kind of firm that can offer a strong track record of projects in which it has designed, built, managed and played other key roles. Systems integrators rely on a network of resources - from expertise providers, through computer hardware and software providers, to equipment suppliers on which a core team of highly skilled engineers can draw to configure solutions to meet particular client needs.

One such systems integrator interviewed stressed the importance of two points - learning by doing ("If you don't build systems for yourself, you don't learn.") and being able to provide clients with demonstrations of the systems actually working and guaranteeing their long-term success.

7. Early users

These are firms that had entered the field early as users of integrated systems and are now selling on their experience. One reason for their doing this is that they were unable to find suitable partners on the supply side capable of carrying through the scale and type of automation project they required, forcing them into a "do-it-yourself" solution. Their strength lies in the fact that they have succeeded and can speak from first-hand experience, but a major weakness may be that they lack marketing experience in the field of automation products.

Notes

1. B. Haywood and J. Bessant, FMS and the Small/Medium-Sized Firm, Occasional Paper No. 2 (UK, Centre for Business Research, Brighton Business School, 1987).

2. Advertisement of the Digital Equipment Corporation.

VI. ORGANIZATIONAL INNOVATIONS

In addition to the technological elements, a number of important organizational and managerial innovations are increasingly finding their way into integrated facilities. Many have been developed in Japan but their origins and applicability are much more widespread. At the heart of these techniques is a philosophy of using existing resources (predominantly the employees themselves) to generate and implement creative solutions to production problems within a context of long-term continuous improvement.

A. Main approaches

Among the most notable in terms of their impact on the kind of problems identified earlier in the report are:

1. Just-in-Time (JIT)

The basis of this approach is simple but it took nearly 30 years' development in Japan, especially in the motor vehicles industry. Just-in-Time or "Kanban" scheduling evolved in the Toyota plants and is now widely used in the country. JIT has now been adapted and is being used in a wide variety of sectors and countries to suit different needs. In its simplest form, JIT allows for minimal batch sizes and inventories. Components are not held in stock but delivered by suppliers to the point where they are needed "Just-in-Time" to be used. Within the factory the same principle applies, with batch sizes reduced so that only sufficient inventory is carried for the task at hand; work-in-progress is effectively eliminated. JIT is as much a philosophy about simplifying production operations as a single technique. Some other benefits are that it brings responsibility for quality, design and process improvement back to the shop-floor.

This means, for example, that:

(a) Deliveries from suppliers arrive just in time to be used by the manufacturer, eliminating the need for high levels of stocks to be held;

(b) Each production stage produces just enough and just in time for the next stage to use it, thus keeping to a minimum the level of work-in-progress inventory;

(c) Goods are produced just in time to be used by the customer, eliminating the need for stocks of finished goods to be held.

The direct benefits are clearly in the area of inventory saving and, given the increasing emphasis of materials costs, this partly explains the popularity of the technique. But in order to effect this pattern of JIT manufacture, there has to be a smooth flow through the plant. This requires streamlining and simplifying all processes and operations so that physical flow is optimized and interruptions due to breakdown of complex machinery are minimized. Emphasis is also placed on changing the approach to quality - from something controlled at the end of the production process to one that is checked and managed at every stage - so that interruptions due to quality rejects are eliminated. Benefits arising from these changes include space savings, scrap reductions, lead time reductions and higher employee motivation.

JIT is clearly well suited to low-variety production. However, it also offers flexibility, which means addressing the problem of reducing set-up time for changing machines, tools and materials in order to manufacture new or different products. The goal of JIT systems is to work economically with a batch size of one - something which challenges conventional theories on what constitutes an economic batch quantity. JIT is thus more of a broad approach than a single technique.

In essence, there are three focal points in introducing a JIT programme:

(a) Reducing set-up times

In order to obtain a smooth flow in a multi-product plant, it is necessary to find ways of reducing the level of interruption due to resetting machines, tooling and other inputs. In a JIT approach, this is achieved in several ways: by reducing the set-up times, by simplifying the sequence of operations required and by standardizing the product and the fixtures associated with it. This does not mean a reduction in product variety but a rationalization of product variants into "families" with similar characteristics representing common operations with minimal resetting of machines. Much can be achieved with the use of standard modular fixtures so that different products can be presented to machinery in the same way, reducing the need for certain position adjustments.

It should be stressed that major set-up time reduction may not be achieved overnight. However, a regular process of improving and streamlining operations, building upon the local knowledge of the operators and maintenance staff who work with the process regularly, can make a significant long-term contribution. One of the most impressive examples comes from the Toyota experience where such an incremental approach over many years has led to reduction of changeover time for large press-shop dies from several hours to single minutes - with corresponding gains in flexibility and productivity (1).

Once set-up times can be reduced, it becomes possible to work with smaller batches without losing product efficiency. In time this can lead to a smooth flow of production in a batch production environment. Benefits include lower inventories (because of reductions in queuing and waiting times) and space savings.

(b) Use of multi-function workers

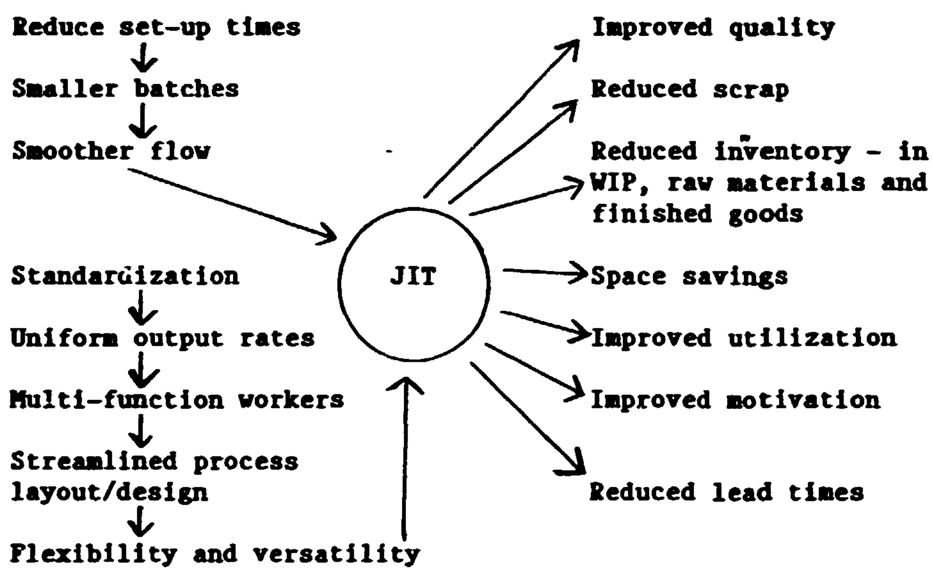
One of the key differences in Just-in-Time production from other systems is the role of the individual worker in the process. Whereas traditional approaches often try and deskill tasks and remove operator involvement and discretion, JIT actively encourages the use of highly-skilled and flexible operators who are able to carry out quality and maintenance tasks in addition to direct operation. By passing these responsibilities back to the line operator, essentially reintegrating them into the overall task, stoppages due to poor quality or to machine breakdown are reduced. This contributes to the smooth flow. Of course, multi-function workers must be trained to perform these additional tasks and in fact a high degree of emphasis on staff development and training is characteristic of JIT systems.

By using multi-function workers within production layouts that have been revised to streamline operations and to stress commonalities, it is possible to achieve considerable interchangeability and flexibility - in routing, product mix, in volume and in coping with staff absences or machinery breakdown.

(c) Uniform output rates

Another element in JIT systems is an emphasis not on volume of output but on the rate of output, stressing the need for predictability and smooth flow once again. This is achieved by standardization - not in final variety to the customer but in the elements of the manufacturing process that can be controlled (fixtures, product families, process routings, etc.). Such standardization helps to provide line balancing even on low volume production; the resulting smooth flow reduces the inventory levels held up in the overall process while keeping production lead times to a minimum. Figure XII shows the interplay among the elements of Just-in-Time.

Figure XII. Just-in-Time: Interplay of Elements



Once again, it can be seen that these benefits represent solutions to many manufacturing problems. This suggests that approaches like JIT are at least complementary to CIM as tools with which to tackle such problems. And they have the advantage of involving much less capital investment since they are primarily organizational innovations. This is not to say that their introduction is necessarily simple; evidence suggests that implementing successful JIT programmes requires a major change in the overall culture ("the way we do things round here") in the organization.

JIT is, above all, a philosophy about solving problems in organizations based on exposing these problems and trying to generate creative solutions using all the skills and experience of the various employees involved.

2. Total Quality Control (TQC)

Total Quality Control or "zero defects manufacturing" is another system that has been highly successful in Japan and is now being applied widely in western factories. TQC is also a broad philosophy rather than a single technique. Its overall aim is to return responsibility for quality to the shop-floor and make it a direct part of the process rather than an indirect activity. Problems leading to quality difficulties such as poor incoming materials are dealt with at source rather than via inspection, scrap and rework, which are really geared around treating symptoms. The aim is to be able to guarantee "zero defects" in production, hence providing 100 per cent quality assurance to customers.

The basic ideas behind TQC are:

(a) Get it right the first time by controlling quality within the manufacturing process;

(b) Make quality easy to see;

(c) Place greater value on quality than on output;

(d) Give responsibility for quality to the individual but back this up with the power to stop production if necessary until the quality problem is solved;

(e) Correct your own mistakes;

(f) Aim for 100 per cent checking rather than relying on statistical sampling;

(g) Concentrate on incremental improvement on a project-by-project basis.

Many of these statements appear trite but not when placed in the context of the quality problem. Estimates for western manufacturing suggest that as much as 20 per cent of all output is below acceptable quality and must be scrapped or reworked. This represents massive cost in terms of delays, lost production and working capital. Further, the extent to which the application of these techniques has been successful in Japan can be gauged by the fact that many Japanese firms can now talk of quality problems in terms of "parts per million" whereas most western firms still deal with "percentage defects" - i.e. parts per hundred.

The tools of TQC include a variety of measuring and inspection techniques designed to identify quality problems at an early stage. Two are particularly significant. Statistical Process Control (SPC) and quality circles. SPC uses a variety of tools to ensure that quality is controlled at each stage in the manufacturing process; if it begins to drift outside acceptable pre-set limits, the process is adjusted to bring it back into line.

Quality circles are essentially problem-solving groups that focus their efforts on a project-by-project improvement of quality-related problems. The aim here, as with JIT, is to harness the skill, experience and commitment of those most directly concerned with production to improve quality within the whole process (2).

3. Group technology

Another important approach in moving to greater flexibility and agility in manufacturing is group technology. This groups products into families and process equipment for making a family in the same place, rather than the traditional flow-line concept which groups different types of process technology together. Such approaches are appropriate for small batch, high variety work and also help in reducing layout complexity. Much of the early work on group technology and plant layout led the way for the development of Just-in-Time manufacturing; the latter still places emphasis on laying out the plant to ensure smooth flow with minimum travel of products during manufacture.

An extension of the group technology concept is the idea of "mini-factories" within a larger plant. In such a facility, al. the necessary inputs to production for a particular family of products, including functional support like quality management, purchasing and stores, design, maintenance and even marketing are grouped together. The result is that, for all intents and purposes, the facility operates like a small factory producing a range of products.

4. Other approaches

A variety of other approaches are beginning to emerge as firms challenge the conventional ways in which manufacturing has been organized and managed (3). Among these are:

(a) Design for manufacture, in which products are specifically designed in consultation with manufacturing (and other functional areas) so as to minimize the range, number and complexity of operations to be performed. This has a number of benefits including reduced lead time for new and modified products, increased productivity (since higher throughput results from having fewer complex operations to perform), better quality and less scrap.

(b) Total Preventive Maintenance (TPM), in which it is acknowledged that much production interruption comes from breakdowns and unscheduled stoppages. In a TPM programme, productive time is sacrificed (for example, a third shift) and devoted instead to a rigorous programme of preventive maintenance. Evidence suggests that the costs of list output are compensated for by the increased availability of the plant during the remaining production shifts, and by the improvements in overall plant utilization figures.

(c) Semi-autonomous working groups, an idea originating in early studies in the 1950s and 1960s in the discussion of alternative forms of work organization (4). In essence, these are attempts at developing some form of group-working in which members are given responsibility for most aspects of production (such as work organization, output rates and quality), thus taking on much of the overall responsibility. As well as improving employee motivation, such approaches can considerably increase flexibility, even in relatively high volume sectors like capital goods or motor vehicle production.

(d) Supplier management, in which the interrelationships between suppliers and manufacturers move beyond the traditional "adversarial" basis (with price as the only determinant) to a more collaborative model (with quality, delivery and technology as important elements within a long-term relationship of mutual dependence) (5).

B. Benefits of organizational innovation

Organizational change is crucial to support the move towards CIM. Put simply, integrated technologies will work effectively only in integrated organizations. The importance of this factor can be gauged from frequent reports stating that 50, 60, 70 and even 90 per cent of the benefits from AMT investment come not from technological but organizational changes involved. This is not really surprising. There is no point, for example in spending £3 million on an FMS designed to give the firm greater flexibility to respond rapidly to changes in the market if the decision-making structure dealing with marketing and production planning remains rigid, slow and bureaucratic. There is also no point in spending a large sum on an integrated CAD/CAM system - allowing data to move straight from design to controlling manufacturing machinery - if the functional areas of design and manufacturing remain separate and operate with little communication.

As this report has argued throughout, many of the innovations discussed are essentially about finding alternatives to the traditional patterns established in the early part of this century. This is as much the case for organizational as for technological innovations.

Consider the following examples:

Example 1

In a firm making small pumps for use in diesel engines, these benefits were recorded after an innovation programme:

Area	Before	After
Lead times	10 days	1 day
Work-in-progress (units)	15,000	1,000
Rejects	3 per cent	1 per cent
Stock turn/year	25	200
Overall costs		10 per cent less

This facility manufactured about 54,000 pumps per month and maintained continuity of production throughout the innovation programme. The investment was paid back within nine months.

Although these benefits might appear to be the result of a major CIM investment programme, they in fact stemmed from the introduction of a Just-in-Time system as an organizational alternative to the traditional way of organizing production. The scheme was devised and implemented by a small team of eight people drawn from the actual operating area, who made extensive use of their "local" knowledge about how things could be improved. The main investment was in a software package called OPT (Optimized Production Technology) which enabled them to calculate the best way to implement the JIT system to avoid bottlenecks in the plant.

Example 2

Area	Before	After
Throughput time	25 days	2 days
Inventory turn per year	5	30
Delayed deliveries	40 per cent	2 per cent
Inventory cost	£10 million	£2 million
Hours (all staff) per unit	330	200
Rework	6 per cent	1 per cent

Once again, this was not an investment in sophisticated and high-cost FMS or CIM but a relatively simple package of organizational improvements and proven manufacturing technology. These benefits were achieved by a Just-in-Time and Total Quality Control package of organizational change and by the replacement of old machinery with CNC machine tools - but not in an integrated configuration.

Example 3

This firm, which makes shock absorbers, increased productivity by more than 25 per cent over a six-year period. During the same period, the following changes also took place:

	1981	1986
Scrap	0.43 per cent	0.23 per cent
Customer returns/ hundred units sold	0.46 per cent	0.11 per cent
Labour productivity (standard units produced/ man-hour)	6.44	8.32

In this case, all the benefits resulted from organizational changes associated with productivity improvement groups. Perhaps most significant, apart from the lack of capital investment, is that these figures were recorded in a developing country, Venezuela.

Clearly, then, it is possible to achieve significant improvements in dealing with the problems identified without necessarily going straight to CIM. It should be stressed that the principles upon which these strategies are based are in no way peculiarly Japanese - indeed, in many cases (such as Total Quality Management) the origin of the idea was in the West - although they have become highly developed in Japan. Nevertheless, they are demonstrably applicable in any country and early evidence suggests that they may be particularly appropriate to developing country contexts.

It is also important to understand that these are not always clearly defined "plug-in" techniques suitable to a particular situation but rather are overall philosophies of production organization and management. As seen earlier in the report, there is a growing range of options being used to address different aspects of the production management process. These need to be part of an overall approach - an organizational change strategy to streamline, simplify and integrate the way things are designed and made.

Above all, the key factor in such approaches is the emphasis on human rather than technological capital. Major improvements in production such as in quality and in productivity can be achieved through relatively simple and inexpensive investments based on people rather than technology.

C. Integrated organizational and technological change

In all the previous examples of organizational adaptation, the common theme is one of integration, of bringing the different elements within and between organizations closer together. Although it could be argued that these various forms of adaptation are simply reflections of the learning curve and experience effect associated with any new technology, a more fundamental change may well be involved - a sort of "second order" learning curve associated with developing a more integrated approach to organization and management.

It is not surprising that integrating technologies should require integrated organizations in which to operate effectively. The problem, however, remains as to how firms should move from the present fundamentally dis-integrated patterns of organization and management towards these more integrated forms.

Evolving a strategy for Computer-Integrated Manufacturing can take two possible routes. One involves what might be called the "techno-centric" approach - installing "islands" of automation based on advanced technology, gradually working towards linking these into a fully integrated "continent", the factory of the future. Problems are perceived as principally financial and technological. The dominant belief is that if enough resources are thrown at the problem, it will be solved.

The alternative route can be termed "organo-centric" - putting the organizational and management changes first. Its pattern follows roughly the prescription of "simplify, integrate, computer-integrate". This implies an incremental approach based on low-risk, high-return organizational changes building up gradually to higher-risk technological changes such as CAD/CAM and CIM. It is becoming increasingly clear that this is the route Japanese manufacturers have been following for some time that has contributed a great deal to their strong competitive position in world markets. Such an approach is not an easy path: the Japanese model and techniques within it such as JIT or Total Quality Control did not evolve overnight but through a costly and time-consuming analysis and improvement programme over many years - but it does offer the prospect of developing a more integrated organization in the end (6).

In the end, manufacturing competitiveness is likely to depend on the ability of firms to exploit Computer-Integrated Manufacturing technology and techniques within an integrated organization. The advantage of taking the organo-centric route is that it involves lower costs and risks and can be planned in advance. The "technology-first" route suffers from the major drawback that, no matter how much money or technology is put in, it will only work if the organization is the right one to support it.

The pattern of progress towards the successful computer-integrated factory is illustrated by a simple matrix in Figure XIII, moving along from cell 1 to cell 4. The organo-centric approach, typified by reported Japanese practice, follows a route based on organizational, followed by technological integration. Many western approaches, in contrast, attempt to move towards technological integration in the hope that organizational integration will follow.

Figure XIII. Approaches to integrated manufacturing

Increasing technological integration →

Increasing organizational integration ↓		
	Current state of factories - dis-integrated technology and organization	High technological integration (e.g. CIM) but dis-integrated organization
	High organizational integration - the Japanese model	Integrated technology and organization

D. <u>The convergence towards CIM</u>

A look at each level in Figure II (in Chapter I) according to its implications on each sphere of manufacturing reveals how convergence takes place towards CIM.

<u>Level 1</u>

(a) <u>Design</u>. CAD is on a stand-alone basis, often applied only to draughting tasks rather than to the full range of design. (This application may well use a low-cost PC-based aid such as Autocad.) By the same token, pre-production planning is automated at a low and unintegrated level - for example, a separate program running on a microcomputer.

(b) <u>Production</u>. Discrete controllers on items of production equipment such as machines, vessels and handling devices may be used for monitoring or direct control, but their range of influence is limited to a single machine and set of operations.

(c) <u>Co-ordination</u>. Again, this involves stand-alone applications, probably running on a microcomputer to manage discrete functions such as stock control or production scheduling, with no direct interchange of data between these programs.

Level 2

(a) Design. This level involves integration of all design activities from concept, through detailed draughting and engineering calculations, to production planning information generation - within a single system. Such a system would probably be a large stand-alone workstation or a mini-computer-based system (although for smaller design areas the range of PC-based systems now offers support at this level).

(b) Production. This level of integration involves linking together the monitoring and control systems associated with a particular product. An example is a Direct Numerical Control (DNC) cell of machine tools and handling and manipulation devices associated with a particular product or a complete chemical plant covering in integrated fashion all the materials preparation and processing associated with a product or range of similar products.

(c) Co-ordination. This level of integration involves bringing together data from different areas to perform a series of tasks. An example is Materials Requirements Planning, which integrates data on stock levels, purchase and works orders, capacity planning and overall production planning.

Level 3

This level links design, production and co-ordination:

(a) Design. The CAD system links with the CAM systems by for example, providing control information for CNC tools directly from the design data base rather than through a separate programming function. Links are also established with the co-ordination system by automatic generation of parts lists and bills of materials which can be used as a data source by an MRP system. Another element would be the use of layout models to assist in optimal scheduling of production, again combining design and co-ordination functions.

(b) Manufacturing. Links are made between design, as indicated, and with co-ordination. For example, the performance and status of the shop-floor would be continuously monitored via a shop-floor data collection system; this information would be used as an input to the planning and scheduling system. The more up-to-date the information, the closer to optimal production the plant can achieve. By the same token, the FMS, which provides for the minimal set-up times and high machine utilization, can be linked to the co-ordination system to ensure optimal use of transport and storage systems.

(c) Co-ordination. The links with design and production mentioned in (a) and (b) operate.

Level 4

At this level, the integration between these spheres of manufacturing in the firm is complete and information flows freely between different components of the total CIM system. Product information is generated on the CAD system, providing a common data base on which all other systems can draw. The whole process is driven by the co-ordination system.

Level 5

At this level, the integrated manufacturing systems themselves a linked with the business and financial information systems so that marketing, price, product and other information can be combined with production availability, design data, etc.

Level 6

Finally, there is a link between firms so that boundaries become blurred on both the supply and distribution side. For example, CAD systems exchange data with each other in joint product or component development; marketing and distribution systems are linked to ensure rapid flow of information and orders; and purchasing can operate on Just-in-Time principles because of the higher quality and more immediate nature of information exchange and availability.

Notes

1. S. Shingo, A Revolution in Manufacturing - The SMED System (Stamford, Conn., Productivity Press, 1985).

2. A good description of quality management techniques can be found in P. Crosby, Quality is Free.

3. For a description of many of these, see R. Schonberger, World Class Manufacturing (New York, Free Press, 1986).

4. For a detailed discussion of socio-technical systems, see E. Mitler and A. Rice, Systems in Organization (London, Tavistock, 1963).

5. R. Lamming, "For better or for worse?: Technical change and buyer-supplier relationships in the UK automotive component industry", C. Voss, ed., Managing Advanced Manufacturing Technology (Kempston, UK, IFS Publications, 1986).

6. For a detailed discussion, see R. Schonberger, Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity (New York, Free Press/Macmillan, 1982).

VII. STRATEGIES FOR COMPUTER INTEGRATED MANUFACTURING

A. Incremental versus single-step moves to CIM

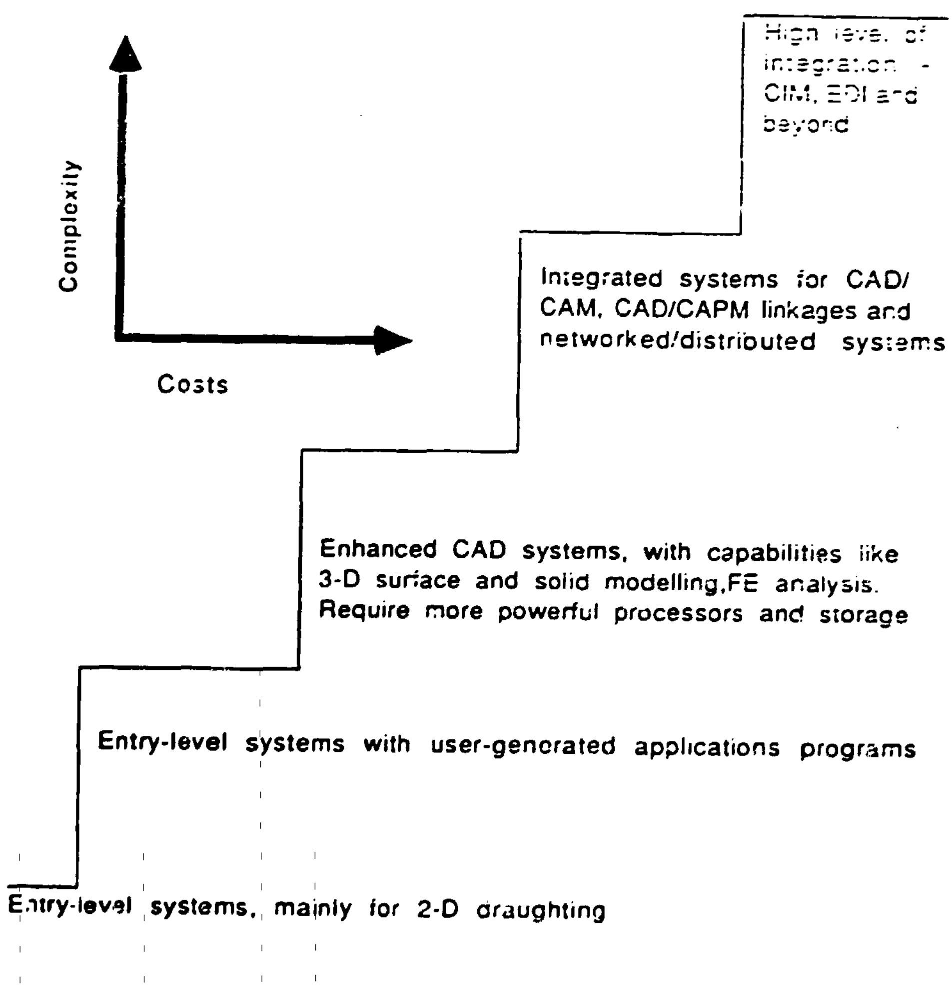
One point implicit in this model is that progression towards full CIM can be seen as a long-term process, part of an incremental strategy rather than something that has to be undertaken in one step. This allows for organizational learning and acquisition of skills and keeps the level of investment required and the risk low in the early stages.

For example, consider the case of Computer-Aided Design:

It is possible to see CAD application on the user side as represented by a ladder with several rungs of experience. Figure XIV illustrates this. Initial entry is fairly simple, using CAD to support basic 2-D draughting work. As users become more experienced, more applications programming can be carried out, and on the back of this, some work using wire frame systems becomes possible. Further experience and investment will permit complex 3-D work. The next stage involves linking CAD systems to other production elements. Finally, the possibilities of CIM and Electronic Data Interchange (EDI) can be explored. (Although this model is based primarily on mechanical engineering applications of CAD, it can equally apply in electronics and other sectors with a similar trend towards greater cost and complexity.)

The same pattern of development via incremental stages can also be applied to other areas of manufacturing as they converge towards full CIM and beyond.

Figure XIV. Stages in CAD experience



B. A general strategy for CIM

The foregoing makes it clear that the full strategic implications of CIM need to be appreciated. Entering this technological field is not simply a matter of short-term investment in one or two discrete items of equipment. Rather, CIM is a long-term philosophy involving technological and organizational components which need to be carefully linked to provide support for the overall business.

Too often, FMS and other AMT systems are installed with little idea of the strategic objectives and the criteria by which to assess the fulfilment of these objectives. Where criteria exist, they are often defined in a narrow technical or financial sense without considering the wider context of the organization's business environment and needs. For example, the success of an FMS is often judged against its cost, its payback and its contribution to cost reduction and output maximization within a small part of production, rather than by increases made to overall organizational responsiveness and agility in a competitive marketplace (1).

To be effective, a CIM strategy has to begin with a thorough analysis of the business needs and with a clear plan identifying the basis on which competitiveness will rest in the long and short term. From this, the key criteria - flexibility, agility, quality, etc. - can be derived.

The next stage requires a review of existing manufacturing operations in terms of their local strengths and weaknesses and their fit with the broad strategic framework. Simultaneously, new opportunities should be thoroughly explored - not only those presented by new manufacturing technologies (such as FMS) but also by new or improved manufacturing techniques (such as Just-In-Time). This analysis enables the firm to develop a coherent and appropriate manufacturing strategy, which will provide the underpinning for meeting the key criteria in the business strategy.

Within the framework of this manufacturing strategy, a long-term CIM plan can then be developed identifying the architecture (the layout of different components); the communications between those elements (and the level of sophistication required in such networks); the hardware and software requirements; and the underlying organizational infrastructure (including suitable skills, functional support and decision-making arrangements). Such a plan would also identify the priority areas and the overall sequence for implementation.

One major requirement in this process is the development of a parallel organizational development strategy to ensure that the necessary degree of organizational integration is available to support the technological developments.

Finally, the strategy can be implemented on a project-by-project basis, moving from islands of automation through to full Computer-Integrated Manufacturing. The advantage of this approach is that it permits the lower cost and risk features of an incremental philosophy to be retained but moves the firm forward within a clear integrating framework.

Without such an approach, there is a risk that far from being a highly integrated "continent" of automation, the factory of the future may instead resemble a loose "archipelago" of islands, poorly joined together by an ad hoc network of bridges and ferries and suffering from the inefficiencies, delays and frustrations associated with such a geography. Table 7 summarizes this CIM strategy.

Table 7. Summary of CIM Strategy

Stage	Action
(1) Define business strategy	- market analysis - competitor analysis - business planning
(2) Carry out manufacturing resources audit	- review all current operations - cost distribution analysis - opportunity audit
(3) Develop broad CIM strategy	- explore options (including organizational innovations) - priorities/sequence - planning
(4) Identify CIM architecture	- specify equipment - specify communications - specify infrastructure
(5) Project planning	- define tasks - allocate responsibilities - define links between projects
(6) Implementation	- resources - timing - controls - organizational development
(7) Continuing audit and monitoring	

C. Implications for developing countries

CIM technology offers a powerful weapon for tackling the range of challenges facing manufacturers. Firms in developing countries (and in many developed countries) have to overcome significant difficulties in moving away from discrete applications of programmable automation and towards integrated solutions. These include problems of high cost, lack of skills, lack of suitable technology (or, often, suitably configured and packaged technology) and a supply market that is still maturing.

For this reason, it is argued that firms with limited resources and experience - such as are likely to be found in developing countries - should concentrate at the technological level on well-proven programmable automation applications (such as CNC machinery, low-cost Computer-Aided Design, low-cost production management aids and basic microprocessor controls for process operations) and use these to enhance flexibility, quality and productivity.

In some cases, the technologies will prove important in removing several production bottlenecks, in saving scarce natural and energy resources and in making up for specific skills shortages. In the long term, it is likely to prove essential that firms in a wide range of developing countries adopt some of the technologies. First, the technologies would help firms advance along the learning curve. Second, the technologies would help develop local capabilities in determining the most appropriate applications, thus contributing towards the development of national technological capabilities.

The adoption of such technologies may, however, carry social costs. Job control, job boundaries, skill requirements and employment levels are altered. Adoption of technology in any context must take into account both the market requirements and the social costs.

At the same time, attention should be paid to the range of organizational innovations outlined earlier which may be more appropriate to the constrained circumstances of many developing country manufacturers. The contribution of such innovations - which require primarily investment in training and reorganization rather than in new technology - can be significant, especially in dealing with some of the fundamental problems confronting developing country manufacturers. Table 8 indicates how Just-in-Time and Total Quality Control approaches might address many of these problems.

Table 8. Potential contribution of organizational innovation (2)

Problem area	Just-in-Time and Total Quality Control improvements
Under-utilization of workers and equipment	Multi-function workers take responsibility for several machines and move to where the work is. When demand is slack, workers can carry out maintenance or quality improvement projects.
Inferior quality	TQC programmes aim to improve all aspects of quality. The low inventories in JIT production mean that quality becomes visible and problems are picked up at an early stage.
Unreliable and long lead times	Multi-function workers and short set-up times smooth flow and reduce lead times. TQC means fewer stoppages for quality-related problems.
High scrap rates	TQC and working in small batches minimize scrap production.
Poor and inadequate maintenance	Multi-function workers include maintenance as part of their task. Planning allows for some production time to be spent on preventive maintenance.
Shortages of raw materials	Scrap minimization helps conserve these.
Shortages of skilled workers	Simpler machinery, quality and production management reduce demand for high-level skills. In addition, multi-function workers will acquire different skills through training.
Lack of appropriate supervision	Less supervision is required with smoother flow and smaller batches. In addition, responsibility for production management, quality, etc. is devolved to multi-function workers.
Poor quality control	Small batches expose quality problems; TQC tackles all aspects of these problems.
Low productivity	Better use of resources (space, inventory, labour, etc.) together with stable or higher output and less scrap, results in higher productivity.

The key then here is that in each area of manufacturing activity there is now a range of choice of improvement opportunities. These range from predominantly organizational changes - where the investment is in human capital, via training and support - to different levels of automation and computer support.

For example, an activity like maintenance can be improved by:

(a) Reorganization of production and training of individual operators to carry out basic preventive maintenance (as in the Just-in-Time approach).

(b) Investments in maintenance craft training to develop and augment skills.

(c) Use of a simple computer system (PC-based) to improve maintenance record-keeping and support a targetted preventive maintenance programme.

(d) Install computer-based monitoring equipment to record information about machinery status, performance and utilization to improve the maintenance data base.

(e) Integrate real-time condition monitoring of key parameters (such as tool wear) with machine and process control systems. Implicit in this approach is a gradual increase in cost, complexity and integration but with a corresponding increase in the level of control over the activity.

Similar choices exist, for example, in energy management. Here the stages might include:

(a) Use of simple microelectronics-based monitoring equipment to record energy consumption on various items of plant and equipment.

(b) Use of computer control systems to respond more accurately to varying energy demand and optimize their use through accurate and fast control of plant and equipment.

(c) Distribution of monitoring system across the entire manufacturing facilities, to provide a total picture of energy consumption. Use of computer-based analysis can calculate where loads can be more evenly balanced, allowing overall reductions in costs.

(d) Integrated energy management systems which use a central computer linked to such a monitoring and analysis network and which calculate control instructions for individual plant controllers so as to optimize energy use.

Once again, the pattern is of a step-by-step approach to the problem using a combination of hardware, software and organizational change - in this case, in the way information is collected and used.

The same approach can be applied throughout the manufacturing facilities and in all areas. For example:

(a) In machining, where the progression might be from retro-fitting microelectronic controls to existing machines, then investment in CNC, then into linked DNC systems and finally flexible manufacturing and robotics.

(b) In process control, where it might involve retro-fitting electronic monitoring, then retro-fitted controls on key parameters, then new plant with integrated monitoring and control loops and finally integrated network control across the entire facilities.

(c) In production management, where basic reorganization and rethinking could be followed by information support systems based on low-cost computers (for example, in stock control) and leading gradually to integrated modular systems such as MRP.

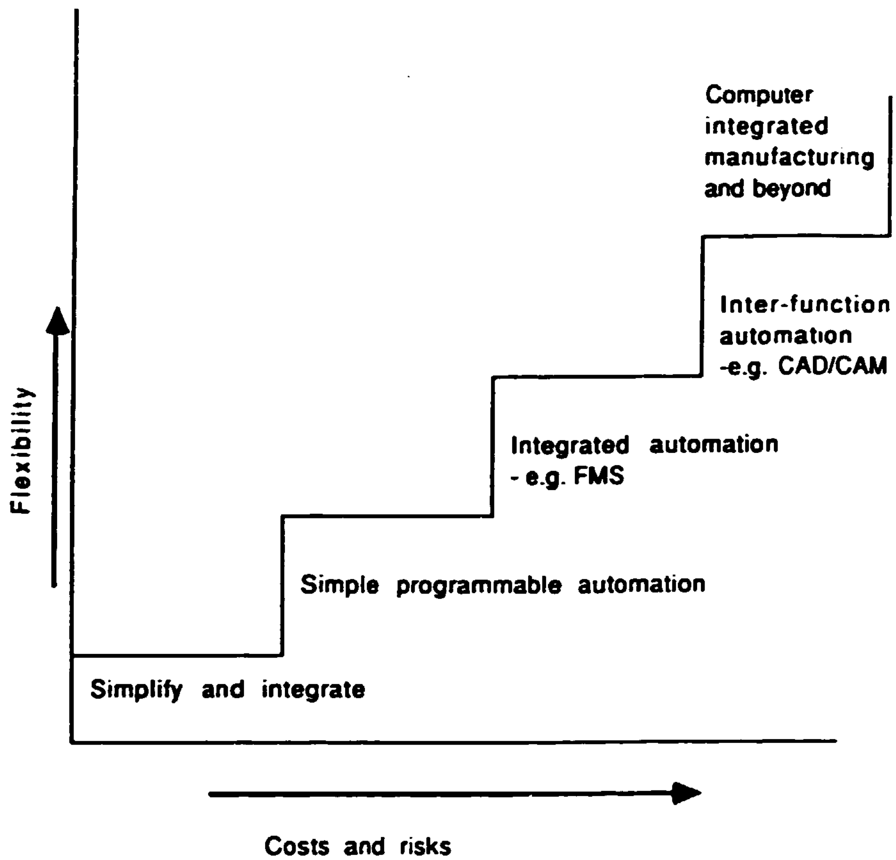
In each case the principle is one of step-by-step progress within an overall strategic framework. Each increment of change is important not only in providing direct benefits but in establishing the foundations (organizational learning, information availability, skills and experience, etc.) for the next.

This is not to suggest that developing countries should not be aiming for full CIM in their strategic planning. Rather, such strategies should be based on an incremental progression from organizational integration with relatively little emphasis on technology, towards more advanced and integrated technological solutions. The degree of CIM required will depend upon the markets in which the firm is attempting to sell, the competitive pressures and the trade-off with factor prices and social costs.

This prescription is similar to that advocated in the industrial countries. The message of "simplify, integrate, then computer-integrate" retains its validity although it might be slightly altered to "simplify, integrate then, if necessary or if advantageous - computer-integrate". The advice given by early users of advanced and integrated systems, stressing evolution rather than revolution, certainly has much to commend it (3).

This recommendation is borne out in Figure XV which derives from the experience gained in implementing many advanced and integrated manufacturing technologies. It illustrates that the degree of risk, cost and possibility of failure increases considerably as firms move towards integrated configuration. The message is again to adopt an incremental approach, building upon organizational improvements and proven discrete applications of programmable automation and gradually building towards full CIM. One advantage of such an approach, if successful, is that the savings generated by each stage in the programme can be used to fund the investments necessary in the next.

Figure XV. Stepwise appro*ch to Advanced Integrated Manufacturing



Notes

1. C. Voss, Managing Advanced Manufacturing Technology (Kempston, UK, IFS Publications, 1986).

2. This table is based on R. Schonberger, Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity (New York, New York Free Press, 1982).

3. Significantly, the UK Department of Trade and Industry has recently restructured its major policy programme of support for AMT to reflect a similar view. Whereas earlier programmes stressed the need for early adoption of new technology and provided direct financial support, the present scheme, entitled "Towards Integration", lays far more stress on the need to take a total perspective and to include putting the organization in order before undertaking major investments in technology.

VIII. POLICY IMPLICATIONS

This final chapter takes up some of the key policy issues in implementing integrated manufacturing technology effectively. In particular, it addresses the actions likely to be important at the firm and State levels.

A. Firm level

The fact that so many firms in advanced industrial countries report that many of the benefits of integrated manufacturing (such as flexibility) come from organizational rather than technological changes suggests that more attention should be paid to improving factors such as productivity and quality via these routes. This is further emphasized by the relative speed and success with which techniques such as JIT have been taken up by firms across a wide range of sectors. Again, the benefits arise from relatively low-cost organizational innovations in layout, procedure and planning, for example. There is a growing body of evidence to suggest that it is via such routes that Japanese manufacturing has become so strongly competitive, rather than through heavy investments in Advanced Manufacturing Technology. Low-cost, low-risk innovations can make a major contribution to competitiveness if reproduced across whole industrial sectors. This is not to suggest that new technology is irrelevant. Rather, it is argued, emphasis should shift away from looking only at the technologies themselves to a more balanced appraisal of the context they will fit into.

The report has already discussed the considerable range of choice opened up in all areas of manufacturing activity by the combination of computer-based automation and organizational change. However, research suggests that attempting to make the transition to full Computer-Integrated Manufacturing in one leap is a high-cost and high-risk strategy. Instead firms should look towards development of a step-by-step strategy within a broad strategic framework. Each innovation step can be used not only to provide direct benefits to particular activities but also to provide the foundation for higher levels of integration. Such an approach has considerable attractions for smaller firms and those in developing countries that face severe restrictions on resources of skills and capital.

A prerequisite of such a stepwise strategy is the formulation of a realistic long-term technology strategy that takes into account both the present strengths and weaknesses of existing manufacturing facilities and the opportunities opened up by new technologies and organizational techniques. This information gathering and analysis will be a key step in the process of strategy formulation and this may require the use of outside expertise.

A clear consequence of the trend towards integration of elements of the production process into new manufacturing systems such as FMS or CAD/CAM is the change in patterns of work organization and employment. In particular, there is growing demand for both new and altered skills to support AMT, in both direct and indirect activities. This has significant implications for training policies. At the level of the firm, it requires that training become much more of a strategic issue. Training has to become much more of a long-term, planned activity, with the firm more closely involved in defining the curriculum and providing inputs and opportunities for on-the-job learning in the skills acquisition process.

In deploying labour in factories using AMT, the integrated nature of the equipment (allied to changes in production organization and to the likely broader and higher skills profile) may mean significant shifts in the firms' approaches to work organization. As has been argued, the traditional models for mass production facilities developed from the early ideas of Taylor and Ford may not always be appropriate in providing flexibility: alternative approaches are being explored in a number of countries and firms. In general, these emphasize more local autonomy and responsibility, a move towards some form of teamwork and an overall decentralization of control back to the production unit.

Firms investing in AMT may attempt to minimize technological and financial risk through a policy of installing islands of automation as stages on the way to full integration. However, these efforts should be related to a clear long-term strategic plan about where the manufacturing facility is going within the firm and what the final CIM arrangement will look like. If not, there is a danger of high levels of incompatibility and possible redundancy of expensive equipment at a later stage. This is not, however, to neglect the important advantages associated with following an incremental innovation policy, particularly in acquiring the necessary experience along the learning curve to be able to determine the most suitable uses of the new technology.

Another organizational change associated with AMT is the need to review conventional cost accounting and investment appraisal procedures. Since investments may be large, they are often difficult to justify on conventional payback criteria. Instead, strategic benefits to the firm must be taken into account - increased or preserved market share, for example - arising from having greater production flexibility. In addition, investment justification should consider materials saving, inventory reduction and overhead minimization through better control. This may require the development of new measures and appraisal techniques. Although labour costs are not as large a consideration in many developing countries as they are in advanced industrial nations, investment decisions will still have to take into account the shift from direct to indirect labour. Some of the technologies may involve too high a social cost in terms of labour reduction which is not offset by other savings or increased sales. There are no clear-cut rules on adoption. Decisions can only be taken within each individual context.

B. National level

The changing pattern in many industrial markets and the trend towards more fragmented and customer specific demand (while still emphasizing non-price factors like design, quality and delivery) means that firms will increasingly need to look for efficient but highly flexible production technologies and forms of organization. The argument can be made that in the future, "economies of scope" - that is, achieved through a combination of flexibility and productivity - will become as important as economies of scale in determining competitiveness. Thus, efforts should be made to promote awareness of integrated manufacturing technologies and, where appropriate, promote their adoption.

The proliferation of choice in systems means that a wide range of firms could, potentially, exploit the advantages of integrated manufacturing. At present, however, most installations that have been identified in developing countries have been confined to discrete applications and most have been within larger firms. Thus, there is a need to support wider awareness and diffusion of the technology or techniques by both sector and firm size. This may well require the development of national programmes taking both a "macro" and "micro" level approach. The latter might best be approached through demonstration projects within individual firms, which could then be incorporated into "macro" promotional programmes.

At the same time, it will be important to ensure that appropriate choices are made when introducing organizational techniques and alternative systems configurations. Until such time as local suppliers are in a position to provide these technologies, there is a similar danger of inappropriate "turnkey" systems being sold that later cannot be easily adapted to local requirements. Both organizational and technological change will require considerable enhancement of national consulting capabilities. This may create a need for "innovation consultants" to assist firms in identifying their most pressing problems and matching them with the most appropriate solutions (be they technical or organizational), and consultants with detailed knowledge and experience on specific technologies and techniques. National governments will need to consider how consultants or "change agents" can best be developed, organized and paid for in support of these activities.

Training, already discussed in terms of the firm level, is also a major responsibility of the State. It was pointed out that the types of training required in support of new automated technologies and organizational techniques are significantly different from previous generations. Courses need to be brought up-to-date so that when awareness programmes have generated an interest, demand can be met. Training courses should also be available to those running the government awareness programme and to consultants who will directly advise firms.

PROPOSALS FOR A UNIDO PROGRAMME

There are a number of ways in which UNIDO could support the adoption and implementation of integrated manufacturing. Clearly it has an important role in providing information. The monitoring of technological trends has always been an important concern of UNIDO and such efforts should continue. As more nations become involved in technological change, UNIDO can operate as a conduit of experience between developing countries, monitoring at the same time changes in advanced industrial nations.

In more direct ways UNIDO could play an important role - for example, in support of national programmes for awareness-raising and training. One example of such a programme (with which the authors have been involved) can be found in Venezuela where UNIDO has supported the training of both government officials and consultants in the area of integrated manufacturing. Such training includes not only familiarization with the range of new technologies and techniques (and their applicability and appropriateness in the local context) but also development of basic diagnostic skills.

The requirement in many cases for effective technology transfer to firms is for potential users of new technology to identify and articulate their particular needs and problems. With this information, it is possible to match up appropriate new technologies and suppliers more effectively. Arguably, the process requires the initial presence of an agent - an "innovation consultant" - who will provide the bridge between firms facing problems in manufacturing and potential sources of technological and organizational solutions. Since the innovation consultant does not need great expertise in the range of new technology available, such intervention skills can be acquired relatively quickly through training.

Beyond such "technology matching" activities, UNIDO could also support a number of demonstration projects. These would have the purpose of illustrating the potential of the new technologies for improvements across the range of manufacturing activity. Of particular importance in the developing country context would be the demonstration of low cost, low complexity options - such as PC-based Computer-Aided Design, Just-in-Time production or computer-aided maintenance - rather than highly complex CIM configurations. A further valuable demonstration would be of a step-by-step strategy for change implemented in a key manufacturing sector within a developing country.

In addition to supporting such demonstration projects, UNIDO could play an important role in developing the infrastructure for consultant expertise in the areas of strategy formulation and implementation. A combination of such skilled resources external to the firm and a technology management development programme for training company managers and supervisors would provide a solid base for implementing the kind of strategy just described. Given the growing interest in technology management as a discipline in many advanced industrial countries, it can be argued that development of this set of skills will be of increasing importance to developing countries.

This underlines a more general point about the relative importance of human resources in the factory of the future. Whether change is effected through reorganization and integration in JIT/TQC programmes, or through investments in advanced manufacturing equipment, the key requirement will be for training and development of staff. UNIDO can play a dual role here, by supporting research aimed at identifying key training requirements and in sponsoring relevant training programmes.

Organizational change has been a major theme in this report but it is important to recognize the difficulties often encountered in implementing such change programmes. By challenging existing and accepted ways of organizing and managing manufacturing, change programmes can result in costly or even failed implementation. Thus, a research area UNIDO could usefully sponsor is in clarifying the dimensions of organizational change required, identifying the barriers to implementing such innovation and developing suitable intervention mechanisms for overcoming these.

At the technological level, a major short-term problem issue is standardization. In theory, all IT-based manufacturing automation uses the same electronic control signals but in practice intercommunication is often difficult. This problem is compounded when equipment from many different suppliers has to be linked; thus the urgency for establishing a universal factory automation standard, preferably based on Open Systems Interconnection principles.

Developing nations have yet to play a major role in the negotiations over standards. Few on their own would have the economic clout to affect the outcome. There is a case for some involvement by international agencies in these emerging issues.

However, it is important to stress that for many applications, simpler networks and communication systems will suffice. OSI lays down valuable principles but for the majority of small-scale factory automation projects, MAP represents too sophisticated an option. UNIDO could, therefore, provide valuable assistance in helping firms define their requirements accurately and to specify appropriate communication networks.