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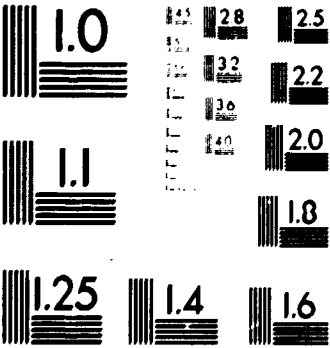

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FLEXIBLE MANUFACTURING SYSTEMS - AN OVERVIEW*

by

John Bessant**

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Abbreviations

AGVs	Automatic Guided Vehicles
AMT	Advanced Manufacturing Technology
CAD	Computer-Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer-Integrated Circuits
CNC	Computer-Numerically Controlled
DNC	Direct Numerical Control
EDN	Electrical Discharge Machining
FMC	Flexible Manufacturing Cells
FMS	Flexible Manufacturing System
FTL	Flexible Transfer Lines
ICAM	Integrated Computer Aided Manufacturing
IPAD	Integrated Programs for Aerospace Vehicle Design
WIP	Work-in-Progress

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Summary

A brief overview of flexible manufacturing systems is provided together with the longer-term prospects for both the technology and its users. A clear definition of what constitutes a flexible manufacturing system (FMS) is not easy because the term has been used by different authorities to mean a number of different things. The essence of the definitions is that they all involve the notion of making small batches economically through the use of some combination of machine tools and handling systems operating under computer control. However, it is clear that FMS is in fact an approach to a particular set of manufacturing problems rather than any single technological configuration.

It is indicated that FMS is not so much a technology as an approach to production of small and varied batches which has a high potential applicability in a number of industrial sectors. Flexible manufacturing appears to be developing along a broad front running from flexible transfer lines suited to large firms with high volume variety production, through medium volume/variety work on FMS to high variety, low volume work in flexible manufacturing cells. Potentially FMS offers to revolutionize small batches manufacturing economics, making use of the economies of scope implicit in the technology. The benefits so far achieved by early users suggest that there will be an increasingly rapid take-up of the technology in the advanced industrialized countries. Although at present FMS is confined to metal cutting activities, the direction of current research indicates that the concept is likely to be applied in all batch-based industries, i.e. castings, forgings, plastics, rubber, clothing and footwear etc. In this context evidence suggests that flexible assembly technology is currently highly developed in sectors like electronics, instruments and consumer products.

Because of the imminent shift in the pattern of batch production it is considered a matter of some urgency that developing and industrializing countries explore flexible manufacturing and assembly in greater depth. The nature of the technology may provide an opportunity for entry into flexible manufacturing, at least at the level of flexible manufacturing cells.

1.0 Introduction

Developments in the field of information technology (IT) over the past 10-15 years have facilitated many new approaches and technologies in manufacturing. Examples include computer-aided design, robotics, computer-aided production planning and management and automated testing and inspection. One of these, which combines both new technology with new approaches to old manufacturing problems, is flexible manufacturing systems (FMS). This report attempts to provide a brief overview of FMS- what it is, where it is being used and with what results, and what the longer-term prospects are likely to be for both the technology and its users.

It would be useful to begin with a clear definition of what constitutes a FMS, but this is not easy because the term has been used by many different authorities to mean a number of different things. Some examples are given below, from which it is clear that FMS is in fact an approach to a particular set of manufacturing problems rather than any single technological configuration:

-" ...FMS is a system which combines microelectronics and mechanical engineering to bring economies of scale to batch work. A central on-line computer controls the machine tools and other work stations and the transfer of tooling and components. This combination of flexibility and overall control makes possible the production of a wide range of products in small numbers. " (1)

-"...a technology which will help achieve leaner factories with better response times, lower unit costs and higher quality under an improved level of management and capital control." (2)

-"...a new breed of automated manufacturing system...FMSs can be programmed to produce an assortment of parts simultaneously or quickly reprogrammed to accommodate design changes or new parts." (3)

The essence of these definitions is that they all involve the notion of making small batches economically through the use of some combination of machine tools and handling systems operating under computer control. As we shall see, the actual choice of configuration is variable and success depends strongly on getting the most appropriate fit for a particular organisation.

It is generally recognised that the first true flexible manufacturing system was developed by Williamson for the Molins company in 1962- the System 24 (4). This permitted a number of different components to be made from a standard block of aluminium and was based on a flow-line principle, with the block moving along to different stations for different operations. Although this represented a major breakthrough (and some versions are still in use today) it was limited by the available technology of the 1960s, particularly in the control sphere. It was not until the advent of low-cost computer control of machine tools and other process equipment in the 1970s that hierarchically-controlled systems began to emerge, first in the form of DNC (direct numerical control) cells with the computer controlling a group of machine tools, and recently the kind of FMS described above which also involves control of handling and overall planning and scheduling.

Before we look at a typical FMS configuration and see how this is achieved, it will be useful to examine where this approach fits into the total manufacturing spectrum.

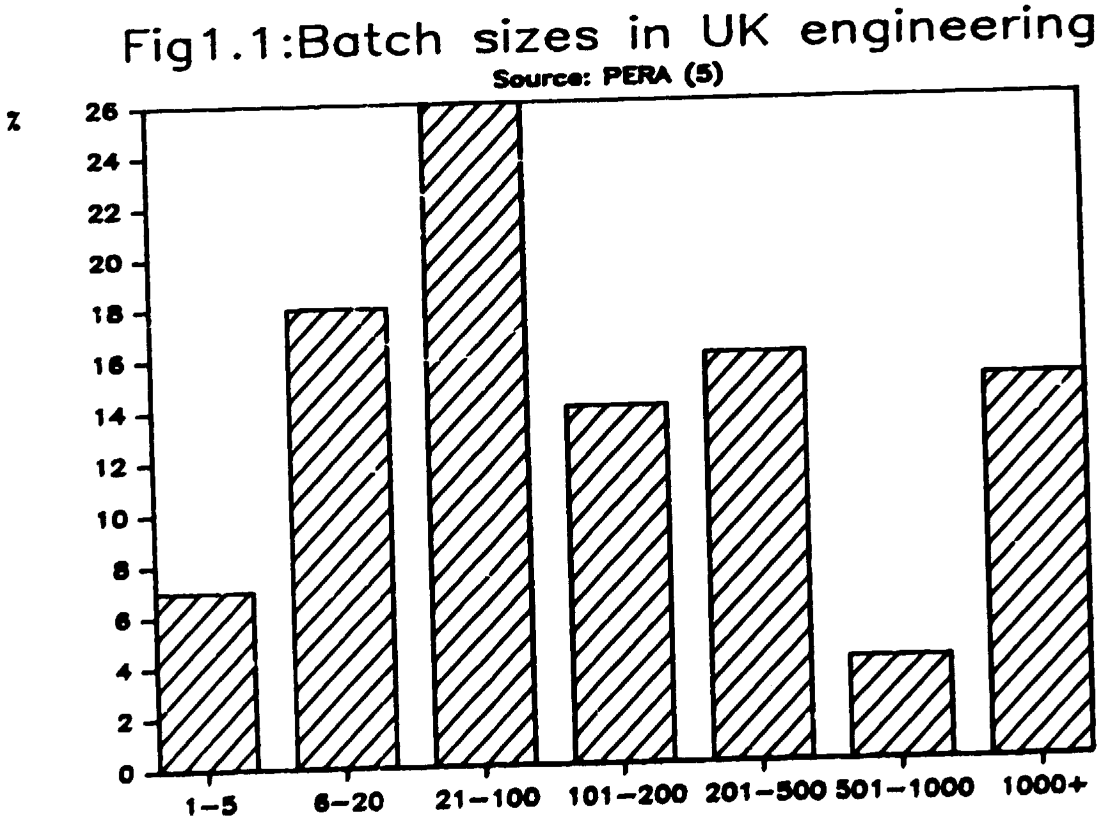
1.1 Relationship of FMS to the manufacturing spectrum

There are a number of ways of classifying manufacturing activities, one of which is to look at the volume of things produced. This excludes those industries which deal with continuous flow, such as petrochemicals, but includes all industries where things are made in batches. Efforts to improve the efficiency in batch manufacture via technological or organisational means have been concentrated on the high volume,low variety end of the spectrum, in industries like vehicles. Here the combination of the organisational ideas of Taylor, Ford and Sloan and the technology of dedicated transfer lines have led to major improvements in costs,plant utilisation,etc, but they involve high capital investment which can only be justified on high volume production.

At the other end of the scale,in the field of high variety,low volume work, recent developments in the field of computer-numerically controlled (CNC) machine tools mean that highly complex parts can be produced efficiently. The traditional problem here has been the time taken to reset machines to work on different batches, but the main contribution of computer control has been to enable these changes to be made in software rather than in the physical setting of the machine itself. Typical examples of this kind of small batch work where CNC has had a major impact are in subcontract engineering where the batch size may be as low as one or two items, e.g. in the production of prototypes for the aerospace industry.

In the middle ground, with batches on average between tens and thousands, the volumes involved are not sufficient to make dedicated automation via transfer machinery a viable option, yet they are too big to be handled efficiently on a stand-alone CNC basis. The vast majority of the engineering industry falls into this category; typical estimates suggest that over 70% of all components are made in batches of less than fifty. Figure (1.1) indicates the average batch sizes for the UK as an example of this. It is particularly a problem in the metalworking engineering sector but is also characteristic of industries like plastics, woodwork,clothing and ceramics.

Figure 1.1 Batch sizes in UK engineering



The problem with small-medium batch manufacturing is that it is inefficient for a number of reasons :

Machine utilisation is low. Even where expensive CNC equipment is used,the actual time spent by a component being machined is very small;most-often as much as 90% - is spent in waiting to be put onto different machines, or for a particular machine to finish the current batch it is working on. One UK report suggests that the door-to-door times-that is,the time taken to move from raw material input to finished product, is around thirty times as long as the actual machining times required. (6);

Because of this there is a tendency to use many machines to keep production going,which represents a drain on both capital and space resources and requires high manning levels;

Manning levels are also high because of the need for extensive handling of workpieces to and from machines and for an army of progress chasers and production controllers to keep track of where different parts and batches have got to in the manufacturing process;

High labour costs often restrict manufacturers from putting on a third (night) shift to improve utilisation because the extra payments required for working unsocial hours would cancel out any benefits accruing from improved utilisation;

The queuing problem of waiting for machining also means that there is a high work-in-progress (WIP) inventory level which represents a high proportion of working capital tied up on the shop floor. High WIP also poses space problems and needs to be kept track of by production control personnel - which reduces manufacturing efficiency further;

Queuing also means that a high level of raw materials stock needs to be carried in order to support the high variety/long lead time production pattern;

Poor utilisation and the other problems mentioned above mean that firms will often try and economise by running longer batches than required to meet orders. Such making for stock increases the amount of capital tied up in finished goods inventory;

The queuing problem means that most of the time is spent waiting and the overall manufacturing lead time is long. This picture can quickly be worsened if there is any kind of machine breakdown-and thus delivery performance is adversely affected. Even in firms with computer-aided design (CAD) the benefits of rapid production of drawings and the ability to transfer instructions electronically to CNC machine tools can be cancelled out by the problems of production bottlenecks;

The overall effect of these factors is a reduced competitive position-one which is often worsened by firms cutting back on the range of products and variety which they offer customers in order to try and minimise the problem of high variety work.

The answer to such problems can be specified relatively easily; what is needed is a manufacturing system offering:

A high degree of flexibility,to handle high variety efficiently;

High machine utilisation;

Reduced materials handling time and costs;

Reduced WIP inventory levels;

Reduced raw materials and finished stocks levels through operating a more responsive system;

Reduced lead times through efficient scheduling and responsive plant configurations;

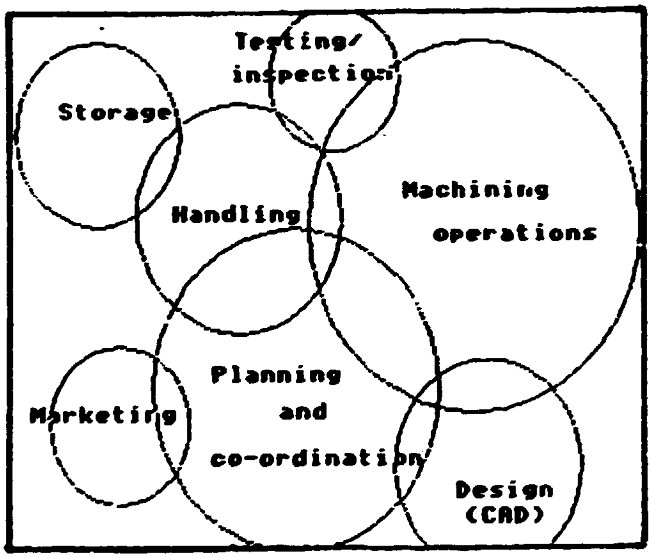
Reduced direct and indirect labour costs, and so on.

Additionally there is the need to distinguish between what might be called "short-term" flexibility-that is,the ability to change quickly between different products in an existing production programme-and "long-term" flexibility,which may mean totally new production programmes in response to the changing market environment. A true flexible manufacturing system should be able to cater for both of these.

It has been difficult to realise this in practice until recently because of limitations of available technology. Nevertheless it is important to note that many of the basic principles behind current FMS have been around for some time; examples include group technology, (in which machines dealing with similar parts are grouped together in a manufacturing cell), computer control of machine tools (both individually in CNC and in cells via DNC) and automated handling of workpieces and tools via multiple heads,fixturing systems and so on.

What FMS does is to integrate developments of this kind, bringing together elements of machining, handling and overall production management. Other options in this integrated pattern include testing and inspection, stock control and management, design (via CAD/CAM systems) and marketing; figure (1.2) indicates this in diagrammatic form.

Figure 1.2 Elements in a flexible manufacturing system

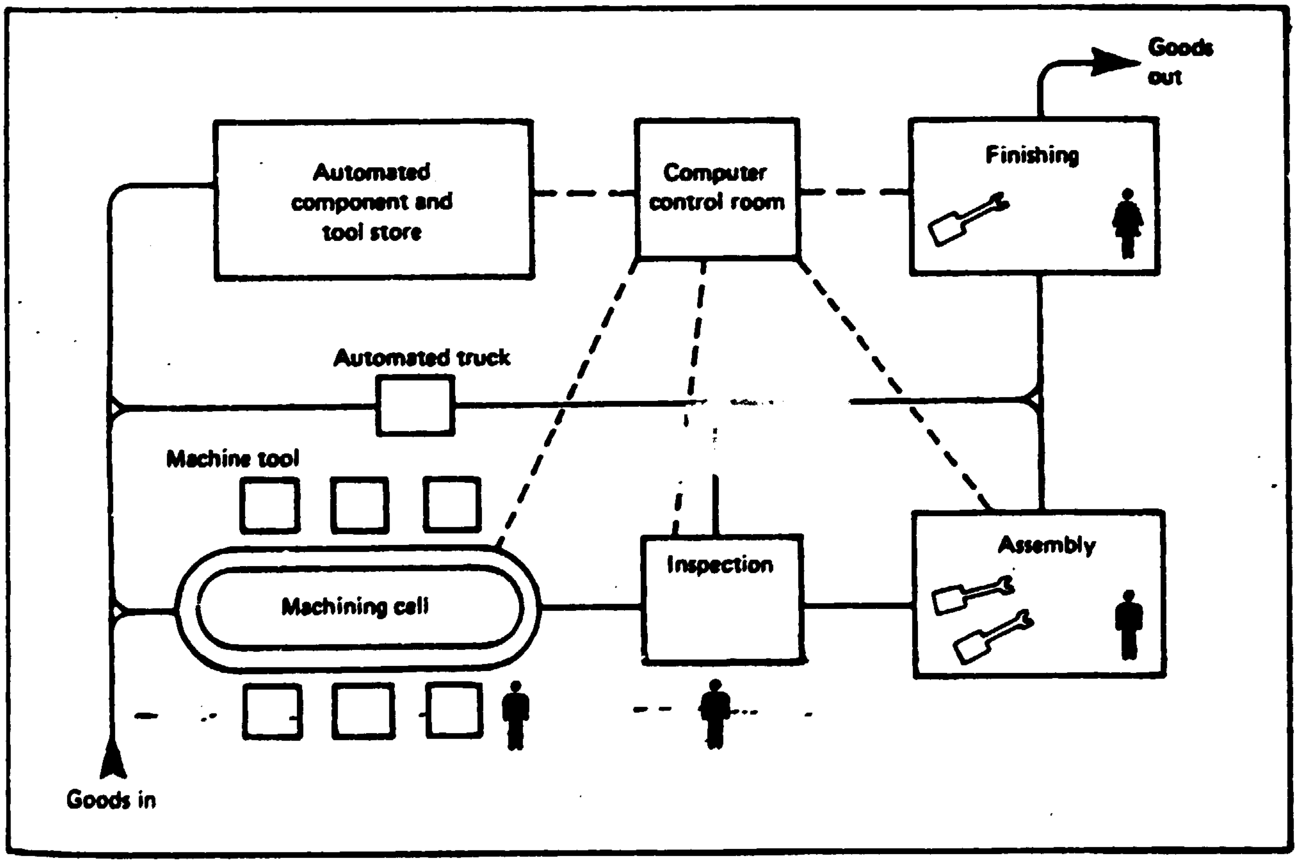


1.2 FMS configurations

There are many ways to achieve a flexible manufacturing system,combining different elements and technological options to suit particular purposes. A typical FMS configuration might look like that shown in figure (1.3) below:

Figure 1.3 Typical FMS configuration

(Source: Ingersoll Engineers (6))



In practice this could be realised in a number of ways; taking the system element by element we can consider some of the choice options.

(i) Storage: -traditional manually operated
-computer-assisted manual operation
-automated warehouse
(ii) Handling: -manual
-conveyor (various types)
-robot
-AGV (automatic guided vehicle)
-towed vehicles
-stacker crane
-lift truck
-overhead crane
(iii) Machine feeding: -manual
-robot
-pallet

(iv) Machine tooling: -manual
-robot
-pallet
-head changer
-magazine
(v) Machine tools: -stand-alone CNC
-machining centres
-single/duplex
-special purpose machines
-in process
gauging/inspection etc
-washing and other support
-laser cutting/

drilling/boring/etc
-EDM (electrical discharge machining)

(vi) Control system:
-DNC
-hierarchical control links with design, production management,etc
-full local area networks
-stand-alone CNC
-manual, and so on.

It should also be pointed out that for each of these areas the options are not mutually exclusive but are usually used in combination.

One consequence of this wide range of choice is that there is no such thing as an "off-the-shelf" FMS; indeed,although many suppliers are trying to offer "turnkey" packages,there are difficulties for them in putting together such a wide range of technologies and skills. The picture is complicated further by the fact that choice is usually constrained by the need to fit into an existing production arrangement; although a "greenfield" site project would be preferred by most FMS users,this is not always possible. There appears to be an increasing role for what might be termed "systems integration contractors" whose role is to put together all the different bits and pieces of technology (hardware and software) into a system to suit a particular set of needs. We will return to this point in our discussion of supply-side characteristics.

Since it appears that FMS configuration is largely a matter of "horses for courses", it will be useful to look briefly at the major influences on choice of configuration.

1.3 Influences on FMS configuration

To a large extent the choice of configuration depends on the type,range and batch size of parts being handled by the FMS. One of the major splits so far has been into "prismatic"-that is parts based around cuboid shapes such as gearboxes - and "rotational" parts such as axles and shafts. The former are suitable for machining on advanced CNC machining centres whilst the latter depend on lathes and cylindrical grinding equipment; the majority of FMS installations are for prismatic types,reflecting the difficulties in handling rotational parts and their relatively lower value. To date no FMS is able to handle both prismatic and rotational parts within the same cell -although this is clearly a direction in which truly flexible systems of the future will have to move.

Most prismatic parts systems make use of pallet-based handling. Conveyors are used to move pallets containing light weight components and those with short machining cycle times, whilst AGVs (automatic guided vehicles) are used to transport heavier components. Since AGVs are slower than conveyors,efforts have been made to develop suitable fixtures to enable one pallet to carry several different components which will mean a longer cycle time at the machines and compensate for the speed disadvantage. Most prismatic systems employ automatic pallet changers and other transfer machinery; many use pallet systems for tool management as well,often employing a tool-changing robot at the machine tool. All FMS in use have some form of automatic tool change and many have head changing ability on machine tools as well.

Experience with rotational FMS is much less developed but here the handling is usually based on conveyors and robot transfer to and from machine tools.

In their report on FMS, Ingersoll Engineers (6) identify the following influences on configuration:

Variety of parts to be handled-the greater the number,the more flexibility required of the machine tools, and may require special-purpose machinery;

Volume of parts to be handled-this will influence the number of machine tools required;

Size of parts to be handled-this will influence the choice of machine tools and the overall space requirements;

Weight of parts to be handled-this will influence the choice of machine tools and also the design of the relevant worktables,shuttles and materials handling devices such as conveyors and robots;

Workpiece material used-this will influence the choice of tools,the horsepower requirements of the machines,the provisions for chip and swarf removal,the cooling systems,etc;

Dimensional tolerance required of the final parts-this will influence choice of machine tools,type of inspection equipment,tooling,fixturing and parts-location technology;

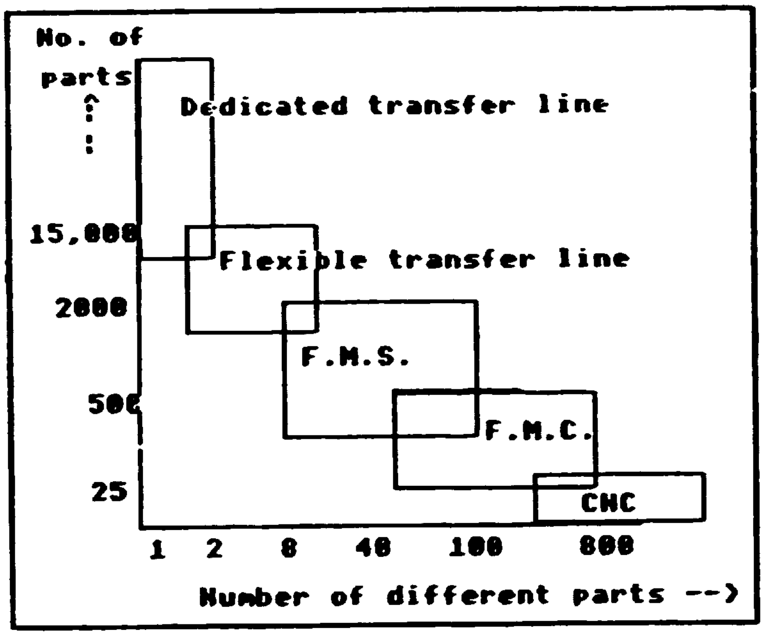
Product life of parts to be handled-short product life will require high levels of flexibility in machine tools and a minimum of dedicated tooling;

For these,and other reasons, users of FMS need to pay careful attention to identifying exactly which parts will go down the FMS. In turn this must be related to the value of the parts involved and how much it presently costs to produce them. It is here that the principles of Group Technology have become widely applied, with a growing emphasis on collecting together "families" of parts which require similar machining operations.

The result,in terms of systems configuration,of this emphasis on parts is that a range of solutions have been developed. These run from systems which are designed to handle high volumes but with some variety and which might more appropriately be called "flexible transfer lines" (FTL), through what has been termed "classical" FMS with a medium mix of volume and variety, right down to low volume high variety applications which are being termed "flexible manufacturing cells" (FMC). Figure 1.4 illustrates this differentiation .

Figure 1.4 Range of options in manufacturing configurations

(based on ISI (7))



It must be stressed that these distinctions are very blurred and the definitional problem is further complicated by use of the abbreviation FMS by some commentators to mean "flexible machining systems"-which can include stand-alone CNC configurations.(8) The effect of this is to make estimates of the numbers or diffusion of FMS technology difficult as we shall see in Section 2. Before moving on to these figures,however,it will be useful to place the range of flexible manufacturing options in a wider context.

1.4 Computer-integrated manufacturing

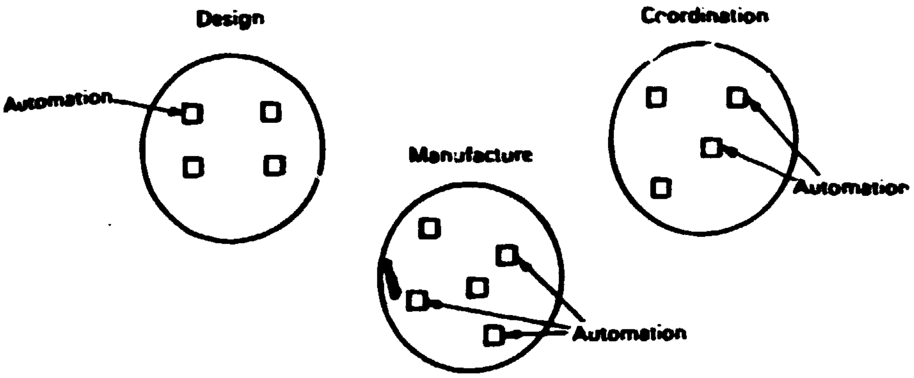
Although significant,FMS is by no means the only computer-based change taking place in manufacturing technology. Most commentators are now agreed that the overall pattern is towards what has been termed computer-integrated manufacturing (CIM)-in which all the relevant activities in a company's operations are brought together under integrated computer control to achieve major improvements in operating efficiencies. Kaplinsky (9) describes this convergence well; he begins by identifying three "spheres" of activity within manufacturing associated with design,manufacturing and overall co-ordination of the production process. Developments in automation technology have been going on for some time in each of these areas and these have led to significantly integrated systems within each sphere; he cites the example of computer-aided design as an illustration. In the case of FMS we can trace the roots back to the earliest generations of manually-controlled machine tools,in which each machining function required a separate machine and operator. Gradually the tasks became integrated into more complex machines and with the emergence of numerical control and later computer numerical control it became possible to reduce the number of both machines and operators required. Further integration became possible with the advent of the multi-function machining centre and with concepts like group technology and direct numerical control which led to manufacturing cells. As we have seen,the present step of FMS extends the integration to the handling and co-ordination areas-and in doing so moves us beyond the manufacturing sphere only.

Kaplinsky argues that although developments up till now have largely involved integration within spheres,the nature of change in the future will be towards integration between spheres. Figure 1.5 illustrates this diagrammatically. As this convergence takes place so the potential for radical change in manufacturing-in terms of a number of parameters-emerges strongly.

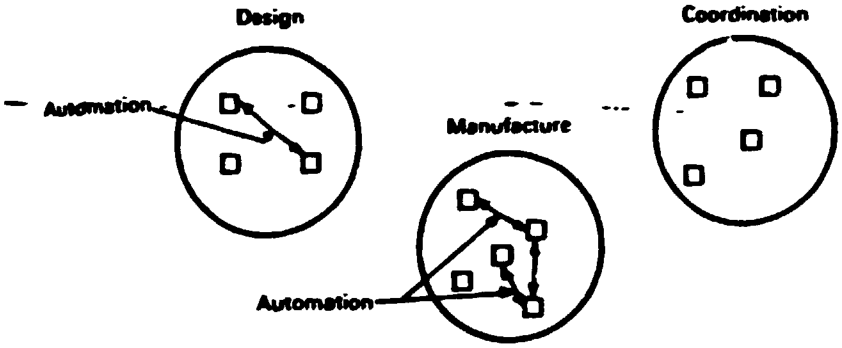
Figure 1.5 Convergence in computer-integrated manufacturing

(Source: Kaplinsky (9))

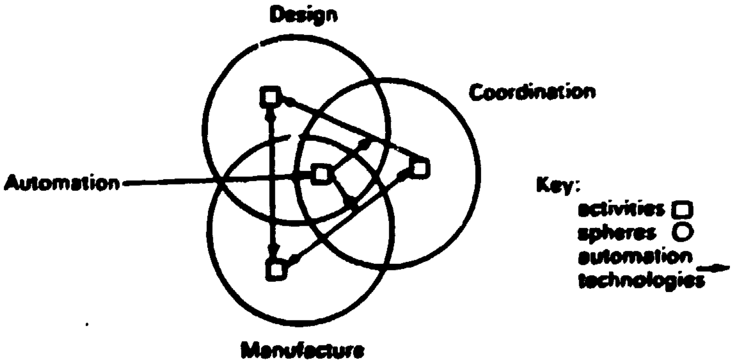
(*a*) *Intra-activity*



(*b*) *Intra-sphere*

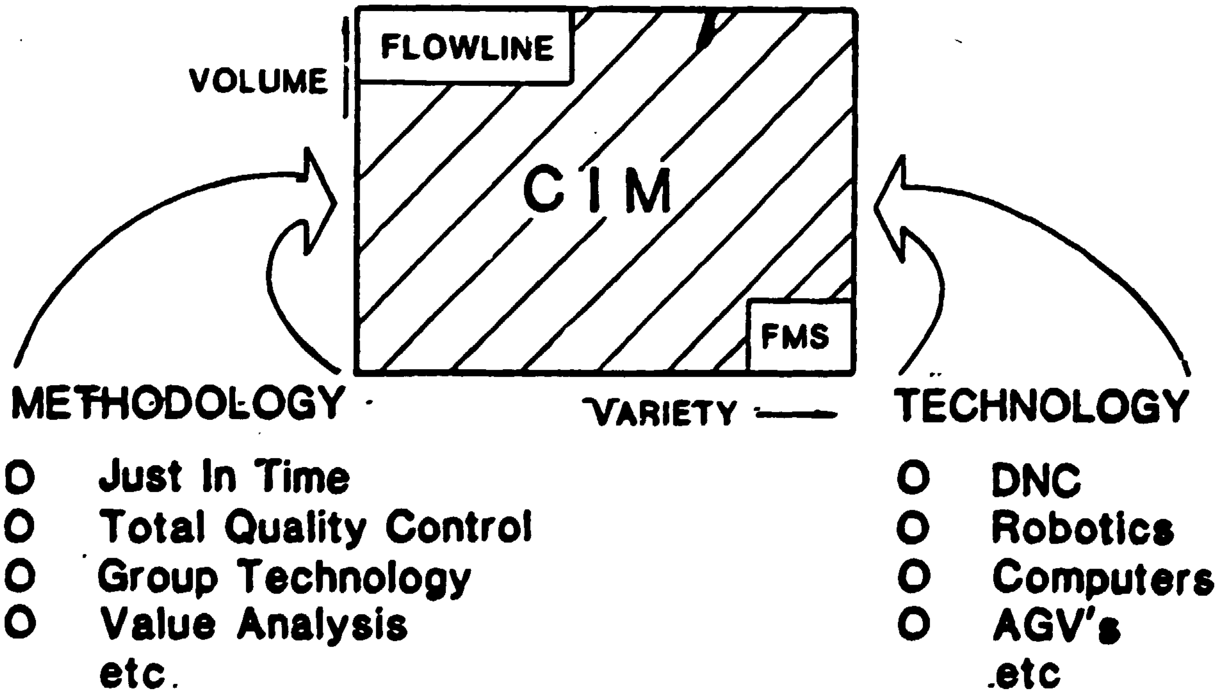


(*c*) *Inter-sphere*



To this must be added the dimension of new approaches to manufacturing methodology; some commentators talk about a revolution or "paradigm shift" in thinking about how production is organised and managed. (10) . To give one obvious illustration, the experience in the developed world has been strongly challenged by the example of Japan,where production management has developed some alternative-and very powerful-tools such as "just-in-time" scheduling and total quality control. (These are described in Schonberger (11) in greater detail; the point of mentioning them here is that the overall pattern of change in manufacturing must be seen as one of proliferating choice from an increasingly wide range of options). Once again,the key to success appears to lie in the ability to choose the most appropriate solution to suit a particular organisation. Figure 1.6 illustrates this range of choice.

Figure 1.6 Options in manufacturing



1.5 Future trends in FMS

From the above it is clear that FMS is still in the early stages of its evolution and is developing along a number of dimensions. These include:

Provision for handling rotational as well as prismatic components. Most FMSs at present handle prismatic components-gearboxes,cylinder heads,etc, because although complex,they can be handled easily by automated systems and machined on sophisticated machining centres. Rotational parts-such as axles- although relatively simpler in shape and cheaper in value are more difficult to handle and require lathes or cylindrical grinding machinery. There are a growing number of this type of FMS, particularly in Japan and the Democratic Republic of Germany-but the pattern of future development will be towards systems which are capable of handling both types of components,thereby increasing the flexibility considerably;

Provision of FMS for sheet metal work. Most FMSs are presently concerned with cutting metal from billets or bars but there is considerable demand-particularly in the aerospace industry- for sheet metalworking FMS. A number of projects are underway to develop such systems and several manufacturers including the firms of Trumpf and Behrens in the Federal Republic of Germany and the US firms of Strippit and Wiedemann are offering sophisticated DNC based systems which utilise techniques like computer-aided parts nesting and which will form the basis of sheet metal cells. The main difficulty in sheet metal work is that it is far less easy to handle and has traditionally been a labour intensive operation;

Provision of FMS for assembly work. This is by far the most significant development area, since assembly operations account for the bulk of engineering work. By inventory, the split is about 60% assembly, 30% machining and 10% raw materials. Some systems are already in operation -eg Olivetti in Italy, Westinghouse in the USA and Hitachi in Japan- and there is considerable R and D effort going into fields like robot vision and sensory systems which will be essential for many of the assembly tasks;

Provision of FMS for non-metalworking activities. The philosophy of flexible manufacturing is applicable to all batch-based industries and development work is going on for FMS in a variety of sectors including metal forging, casting, plastics moulding, clothing and footwear;

Sensor technology. The importance of continuity in automated operations means that there is a growing need for in-process inspection and monitoring; much research is now going into a variety of techniques and equipment. These range from the conventional electromechanical " touch trigger" systems currently in use to advanced optical methods employing lasers and video technology. The advantage of using lasers is that it opens up possibilities for non-contact inspection and measurement;

Control systems. Characteristic of FMS is the high level of computer-based control over the manufacturing process. The pattern of development is moving towards an information hierarchy with several levels running from individual machine/ process operation (such as handling or transport or tooling) control, through a local supervisory DNC link and up to an overall computer which will interface with other production operations including scheduling and planning and possible design. This in turn requires software which will enable all the different elements to talk to each other-and considerable research is going into software development and particularly standardisation and compatibility questions. The longer-term prospects offered by artifical intelligence in this connection are interesting; significantly one of the major projects in the European "fifth generation" programme ESPRIT is on development of software integration methodologies for factory automation;

Handling and transport systems. Options in these areas are already extensive and this range is likely to grow with the emergence of specialist handling equipment for particular duties. In this field robotics will be the major growth area, particularly as second generation equipment with sensory capabilities becomes available;

Communications. In order to link together the various elements and computer systems some form of communications network is needed. Hitherto this has been via simple cables which are limited by cost and physical routing considerations; however, longer term developments include optical fibres which will carry various forms of signal at high speeds and densities. In terms of organisation of communications the trend is very much towards the use of local area networks- a kind of ring main for communications;

Tool management. With the growing emphasis on flexible systems comes equal pressure for flexible tooling provision. Tools can be expensive,particularly since high cutting speeds need specially hardened materials and the trend is towards computer aided systems for efficient management of these such that the minimum number for continued operation are used. In turn this implies a need for standardisation of tooling and cutting programmes which links into the whole question of designing parts to be manufactured by an FMS;

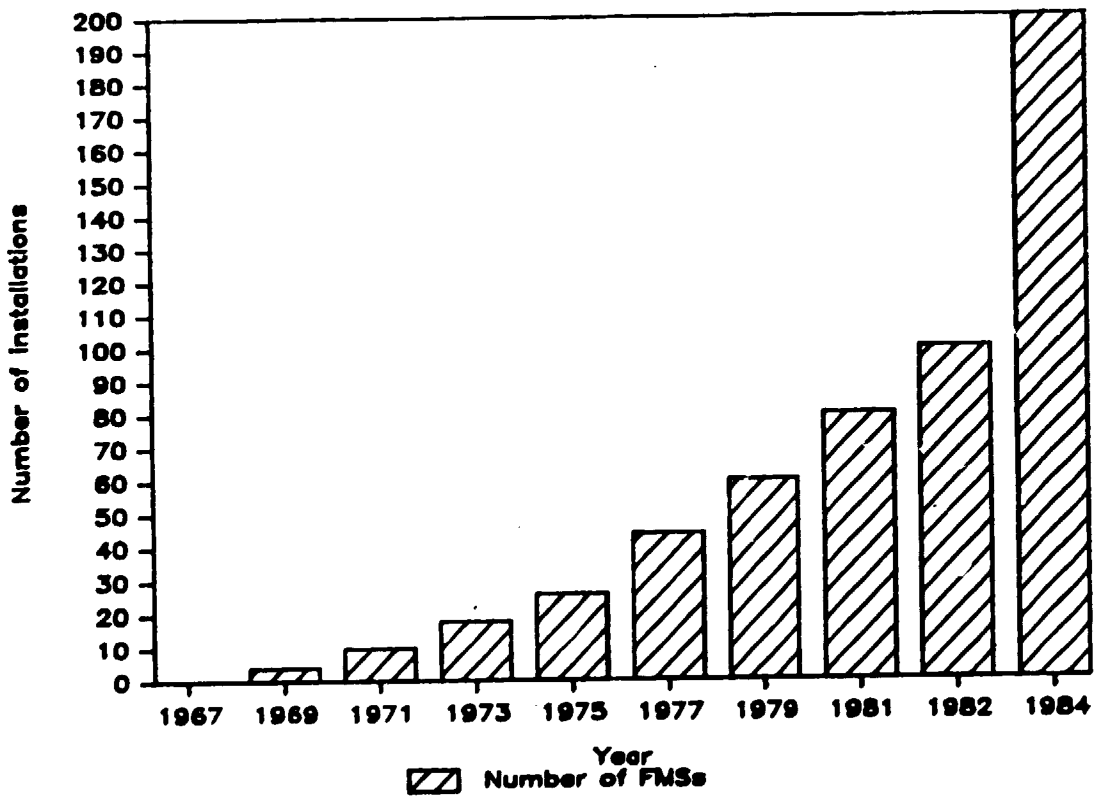
Developments are also taking place in the field of robot setting and adjustment of tools and in in -process tool wear monitoring and computer-aided replacement programmes, all aimed at reducing tool breakages and subsequent downtime on the system;

Laser technology. ne of the key areas of development is in the possible use of lasers in various stages of the machining process. We have mentioned above the possible use of this technology in inspection and in-process measurement work, but there is also considerable potential seen in applying lasers as tools themselves. Suitably controlled lasers can cut, drill, bore, weld and carry out other operations which would eliminate the need for conventional tooling; this would reduce setting times dramatically and also cut the downtime on machines since it would eliminate problems of tool wear or breakage. Several research projects, notably the Japanese Flexible Automation with Laser system at Tsukuba which is using a laser to cut and weld and another to handle cut swarf chips, are exploring this option.

2.0 Applications and distribution of FMS

As we have already noted,there is wide variety in definitions of FMS and consequently it is difficult to obtain accurate figures for the numbers of FMS currently in operation. Figure 2.1 gives a compilation from various sources which indicates rapid growth from one system in 1967 to a present level of perhaps 150-200. Table 2.1 presents this data broken down by country-and whilst the figures presented by different researchers indicate variation in definitions used, the overall picture is clear. Japan leads the world with the USA second with roughly half that number of installations, and with Europe, particularly the Federal Republic of Germany, responsible for most of the rest. This picture is not really surprising in view of the high capital costs involved in FMS and also the early stage which the technology is at; most users of FMS will admit that their investment is partly to place themselves on the learning curve so as to be in a better position to exploit later generations of FMS. There is -again not surprisingly-a strong bias at present towards large firm applications (table 2.2), and the range of industries represented are often involved in volume production, such as in the vehicle industry, although the FMS is used to produce medium batches of complex parts such as cylinder heads or gearbox covers. (Table 2.3). There does appear to be some regional variation in this,which can largely be accounted for by historical factors. In the USA most FMS has been developed to meet the needs of large companies in the defence and aerospace fields. The result is costly but technologically very sophisticated systems which are not really appropriate for smaller firms. A similar pattern can be found in Scandinavia. By contrast the Japanese approach is based on much more of a medium level of technological sophistication aimed at a wider range of parts and company sizes. Significantly the government direction of work has been towards systems for the smaller firm and early evidence suggests that far more parts are being put along FMS in Japan, reflecting not just the flexibilitiy of the systems but also the wider range of firms using them (12) . In Europe the trend has tended to follow the Japanese example with applications for smaller firms receiving support, although there are also a number of large installations with a very high degree of sophistication,particularly on the control side. Table (2.4) indicates a comparison of the number of different product types put along FMS in different countries-an indication of their flexibility- whilst Table 2.5 gives similar data for batch size. Table 2.6 indicates the variation in configuration-a somewhat crude assessment based only on numbers and not complexity of machines. Table 2.7 indicates the split between rotational and prismatic parts and Table 2.8 the different types of Japanese installation. From this early data we can draw some tentative conclusions. First, there is still room for development of FMS and particularly for systems to meet smaller batch requirements in the FMC area-a theme which we will return to later. Second, although the present pattern of use indicates the lack of maturity of the technology, it is expected to grow rapidly in the next five years (13). Most of those firms currently using FMS consider it to be in an early state of development and many system are explicitly designated as learning or demonstration projects. Nevertheless, the experience gained from running these, whether in FMS,FTC or FMC configuration, does suggests that major improvements in productivity, quality and other performance variables are possible. Even where the individual batch sizes are low, the reduced setting and queueing times mean that aggregate production volumes are high - and consequently, that flexible manufacturing offers considerable competitive advantages over conventional batch production techniques. This makes it a matter of some urgency that countries not yet exploring its possible application begin to do so. The experience of the above users suggests that a variety of configurations have been implemented to suit different batch and firm sizes and product ranges, therefore, that it is possible to identify particular niches in which FMS can be applied which are compatible with organisational or national strengths and weaknesses in manufacturing. It is dangerous to generalise too far, however, from such early data. More information can be gleaned by considering the particular experiences of users of FMS, and we will consider a few such cases next.

Figure 2.1 Worldwide growth in FMS



(compiled from Hatvany et al (14), Rathmill (15), ISI (16), Young et al (13) and National Economic Development Office (NEDO) (8))

Table 2.1 Worldwide distribution of FMS

Country	1980	1981	1982	1983
Japan	28	30	33(b)	37(d)
USA	15	16	-	-
	6(a)	7(a)	9(a)	15(a)
	14(b)	18(b)	19(b)	-
				16(d)
FRG	10	13	13	-
	8(b)	9(b)		
Sweden]	8	8	8(c)	-
Norway]			1(c)	-
Czechoslovakia	4	5	6(a)	-
UK	3	4	4	4(c) 8-10 (1984 e)
DDR	3	3	5(a)	-
Hungary	-	-	5(a)	-
Poland	-	-	5(a)	-
Bulgaria	-	-	3(a)	-
Belgium	2	2	4(c)	-
France	-	-	3(c)	-
USSR	2	2	-	-
Rumania	-	-	1(a)	-
Total worldwide	64-75	68-83	100-110	100

(N.B. The variation in the above figures arises from different definitions of FMS by researchers)

Sources: Rathmill et al (15)
(a) Hatvany et al (14)
(b) ISI (16)
(c) NEDO (8)
(d) Young et al (13)
(e) Bessant and Haywood (17)

Table 2.2 Distribution of FMS by firm size (1981)

Country	2000 employees	2000 employees
Japan	2	24
USA	-	15
FRG	5	10
Total	7	49

Source: ISI (16) (based on sample where n= 80 systems)

Table 2.3 Distribution of FMS by industrial sector (1982)

Industry (n=80)	
Truck and tractor (excl engines)	20
Machine tools	19
Mobile equipment (incl construction equpt.)	17
Engines (diesel,aircraft,prototypes)	8
Machinery (incl office,printing,mining)	6
Aerospace	6
Other mechanical and electrical engineering	19
Experimental installations	5

Source: NEDO (8)

Table 2.4 Flexibility of systems;number of products in range (1981/2)

Country	5-10	10-100	100-200	200
Japan	6	8	3	2
(n=22)	4(c)	11(c)	1(c)	2(c)
(n=35)	12(b)	18(b)	-----5-------(b)	
USA	12	2	1	0
FRG	2	3	8	2

Sources: ISI (16)
(b) Young et al (13)
(c) Hatvany et al (14)
(d) Sackett (18)

Table 2.5 Average batch sizes in FMS installations

Batch size	Japan (b)	FRG (a)	USA
1	3 0 (c)	10%	0
2-10	3 7(c)		12
11-30	7 3(c)	60%	2
31-100	8 3(c)		
101-500	2 4(c)	20%	1
500	2 0(c)	10%	

Sources: (a) ISI (16)
(b) Young et al (13) (n=49)
(c) Hatvany et al (14) (n=22)

Table 2.6 System configuration: number of machines involved (1981)

Country	2-5	6-10	11-15	16-25	26-30	31-35	Ave.
Japan	18	8	4	2	-	-	7
USA	2	10	4	-	-	1	11
FRG	5	5	2	-	1	1	10
Europe (excl FRG)	7	8	1	1	-	-	6

Source: ISI (16)

Table 2.7 Distribution of systems by part type (1982)

Country	Prismatic	Rotational
Japan	29	8
	24(b)	9(b)
USA	18	1
	17(b)	2(b)
UK	3	1
FRG	13(b)	4(b)
Europe (excl FRG)	12(b)	5(b)

Sources: Young et al (12)
(b) ISI (16)

Table 2.8 Japanese distribution of systems by component types and
system types (1982) (n= 53)

	F.M.Cell	F.M.System	F.Transfer Line	Total
Prismatic	4	29	9	42
Rotational	1	8	2	11

Source: Young et al (12)

2.1 Examples of FMS installations

(i) Yamazaki Co, Oguchi, Japan (19)

This plant was designed specifically to employ FMS concepts and to provide a learning base as well as a production operation. Experience gained in running this site was used to design the new Mino Kamo facility and other plants producing Yamazaki products (including one in Florence, Kentucky, USA and the projected Worcester,UK plant). It was probably the first full attempt in Japan to build an FMS and took two years to complete; operations began in October 1981. In configuration it involves two FMS lines; line A contains 8 and line B 10 machining centres. Both operate under full DNC and have automated swarf removal systems. Careful attention to product design allowed considerable tool standardisation, with line A using only 63 and B 44 for the entire product spectrum. Tool changing on A is automatic,based on a magazine system whilst B still has manual changing. The products are all for the Mazak range of machine tools; line A makes 23 different parts of cast iron with a maximum weight of 3 tonnes, and produces around 800 per month. Line B makes 51 different product types with weights up to 8 tonnes at a rate of around 600 per month. Materials handling is by an AGV/pallet system ; line A has 44 work pallets and line B 29. These are loaded manually by four operators and there is provision for storing 16 pallets on line B to permit unmanned night shift operation. The computer system involves 8 separate computers arranged in a hierarchy governed by a PDP 11/23 minicomputer. It handles 74 workpiece types, over 1000 tools and a throughput of around 1400 workpieces /month. The main benefits are summarised in table 2.9,below.

Table 2.9 Main benefits of FMS

	Conventional machining	FMS
Operators	215	12
Work-in-progress (no. of items)	2760	120
Throughput time days	35-90 days	2-3
Space required sq m.	6500 sq metres	2790
Number of machine tools	68	18

Additional benefits include savings in salary costs (around £1.5m), savings in interest charges due to improved capital utilisation (around £0.5m) and a dramatic cut in the overall product lead times. Whereas it took four months to produce a CNC machine tool on conventional systems,this has been cut to one month.

The system cost around £10m and took two years to pay back this investment,operating on the basis of near-continuous 3-shift operation. Figures for 1983 suggest that utilisation was about 95%; this can partly be explained by a deliberate policy of running the machines at less than optimal cutting speeds in order to reduce tool wear and breakage with its consequent need for stopping the line.

(ii) Yamazaki, Mino Kamo, Japan (19)

Following the successful experience of Oguchi, Yamazaki have invested in what is currently the world's largest FMS facility in a new purpose-built factory. This cost around £40m for the initial phase alone and took two years to build; in essence it represents an increase in both the scale and breadth of the Oguchi operations.

The plant employs 240 people operating 60 CNC machine tools with 30 robots; the output is again CNC machine tools (lathes and machining centres) with output figures of around 150-200/month. As with Oguchi, the FMS forms part of the overall assembly and finishing operation; in this case four groups of products are handled-flanges,spindles,gearboxes and frames.

Automated warehousing is used and handling is carried out by pallet loading robots rather than manually. Transport is by AGV and machines are fed with tools and workpieces by pallet systems. In the computer area there are five separate systems covering transport, rotational parts (spindles) FMS, prismatic parts and environmental management.

Less data is available on the performance of this facility but output statistics for the whole plant indicate a reduction from 12 weeks to 4 for lathe production. Payback of the investment could have been within four years on 3-shift operation but this has not yet been implemented.

In the USA another 2 FMS line plant was opened in Florence, Kentucky to produce a total parts range of around 180 with a similar mix to Mino Kama; this greenfield site plant employs only 15 workers on the day shifts and does operate an unmanned night shift supervised by four control personnel.

Significantly Yamazaki has recently announced plans for a £30m investment in a plant in the UK which will employ 200 and produce a range of five machine tools. The configuration is similar,again with 30 robots and AGV/automated warehousing handling.

(iii) Normalair-Garrett, Crewkerne,UK

This was the first FMS in the UK and is located within an existing production facility. The company are involved in aerospace work and batch sizes are small, with the average around 25 and with many as small as 5-off. An additional problem is the low repeat rate of production which means that there is a high set up cost associated with each product and high work-in-progress inventory. The company approach to the problem was to specify a requirement for a new system which would handle prismatic parts and:

" -minimise labour
-minimise WIP
-eliminate stocks
-minimise lead times
-maximise profitable output
-optimise manufacturing flexibility
-increase turnover per operator
-achieve these objectives within an acceptable investment level
-minimise paperwork " (20)

The project commenced in 1979 and was initially aimed at producing an ejector release mechanism for the Tornado aircraft; initial production began in mid-1981. The system cost around 1.1m and the company received a grant of around 30% from the UK government under a special programme designed to promote the take-up of FMS.

The configuration involves two large machining centres with auto tool change and pallet feeding. Transport is by AGV and parts are loaded manually. Each machining centre has automatic tool and head change,giving them the flexibility to produce a range of 10 complex parts. (Although the entire release mechanism requires 100 components,70% of all the machining required is on these ten components). The entire system is under computer control and there is a link between this site management computer and the company's main factory some 20 miles away.

Benefits reported so far include the following:

Output/operator raised from £ 67,000 to £ 209,000 per year;

Turnover of stock and WIP raised from 3.3 times /year to 24 times;

Manufacturing lead times cut from 17 weeks to 2 weeks;

Low in process scrap;

Zero assembly failures;

Zero customer rejections

(iii) UK motor components manufacturer

This company is involved in engine and component production in the UK and decided to invest in FMS technology at an early stage in its development. The case is interesting because it indicates some of the problems involved in making large investments with long lead times, and because it highlights the question of how much flexibility there is in such systems. In the original plan the system was an advanced flexible transfer line designed to handle the machining of crankcases; the total configuration included 9 machines many of which were equipped with automatic tool and head change and advanced fixturing enabling different faces of the case to be machined simultaneously. Overall costs of the system were about £4.5m .

In terms of the original objectives-a reduction in the cycle times required for machining different cases- the system was a success, cutting the cycle time down to 20 minutes per case. Unfortunately the investment was made in expectation of market expansion, whereas the reality was that the market for these products contracted drastically -with the result that the line has considerable excess capacity because of its efficiency. For this reason they have been forced to look at different ways of using the line to improve its utilisation and they are looking at running different types of components down it. These include different materials, aluminium as well as cast iron, and different part sizes.

The new system costs around £ 500,000 extra although much of this cost is due to new tooling requirements for different components. Whereas the initial line was semi-dedicated, the switch to fuller flexibility requires a more advanced DNC link on the CNC controlled machines and in the longer term they may well invest in robotic handling of some kind. There is no doubt that if they were designing an FMS to handle their current wide range of parts from scratch they would not have chosen this configuration. Nevertheless, the fact that an extra investment of 10% and one year can convert a semi-dedicated flexible transfer line to an FMS indicates the nature of the flexibility in this approach to manufacturing. The benefits are not only in capital savings (returning to a conventional stand-alone configuration would have cost more than the adaptation of the FTL) but also in experience of FMS; as one production engineer put it, "I believe we now have more experience than the machine tool suppliers in how to make things more flexible!"

(iv) UK engine manufacturer

This firm produces large engines for industrial and marine duties and has recently invested around £800,000 in a large FM cell based on two large machining centres. Batch sizes are small and the nature of their market means that there is high variety between batch types; current market uncertainty has exacerbated this problem. Their main concern is the high cost of inventory tied up in the manufacturing process. Their FMC development is the first stage of a larger programme which will include a second FMC , CAD/CAM links and an overall operations control hierarchy covering stock and materials control, shopfloor scheduling and production management and control.

The present FMC is designed to handle a range of cylinder heads at the rate of around 100/week - but it is flexible enough to switch to building complete engine sets of sixteen different components. On the costs of £ 800,000 payback is expected within three years, based on a saving of £100,000 per machine in inventory and manpower costs plus an expected additional £150,000 per machine per year saved in time and other overheads.

(v) UK electronics firm

Not all FMS is confined to metal cutting work; in this example an FMS has been developed for use in the manufacture of printed circuit boards for the electronics industry. This also borders on the idea of flexible assembly mentioned earlier.

The problem at present is that the electronics firm makes around 1600 board types of which 840 are what they term "active" at any time. Analysis revealed that only about 220 of these accounted for over 70% of production, but each of these was a highly complex board with a component count of around 3500 and a potential combination of these of around 5 million options. Present manufacturing is done by a workforce of 53 direct and 6 indirect staff using a combination of automatic, semi-automatic and manual insertion equipment.

The FMS is aimed at these 220 boards although others may be added to the range later; volumes are around 80,000 boards per year. Current production is heavily dependent on manual intervention and takes around 3-4 week per board; the proposed FMS is expected to cut this to 6-8 hours. This is based on a configuration of 9 special purpose machines, robotic feeding and insertion, automated inspection and testing, AGV-based handling and overall computer control.

Overall costs are estimated at around £ 2.5m including £90,000 for training and 155,000 for special software and controllers. Payback, based on labour savings and lead time reductions, is expected to be 3.5 years but this will reduce to 2.5 years if a government grant is made available.

(vi) Other non-metal cutting examples

Other areas in which FMS technology is being developed include:

Sheet metal work- one aerospace manufacturer is working on a system which will handle a massive range of up to 25,000 different components in an average batch size of 42. Estimated costs are between £7m and £ 9m , although much of this will be in new sophisticated machines to replace outdated conventional plant. The main aim is to save labour (around £700,000 per year) and WIP inventory (around £100,000 per year);

Metal casting - the Steel Castings Research and Trade Association in the UK is working on linking robots and CAD systems to a new process for high precision steel castings. This will form the basis of a flexible casting system in which changes in component design can be quickly accommodated with minimal scrap and WIP. The expected costs will be around £500,000;

Garments - various projects are now underway - such as the "FIGARMA" system in Sweden - which aim to develop flexible assembly technology for the garments industry;

Woodworking - recent investment in a UK firm of around £500,000 has illustrated the applicability of FMS principles and techniques such as robot handling and computer controlled machining and overall shop sheduling in other materials industries such as wood. The system has improved the utilisation of the cutting machinery from 25% to over 70%. As the consultants responsible for the system explained, there is no real difference between input raw materials- the principles of FMS apply across the board;

Metal forging - in a development plant Westinghouse (USA) have invested around $5m in a system to produce turbine blades of various sizes and lengths. The configuration includes automated handling, machine-vision system based parts identification and gauging, computer controlled swaging, cropping and stamping and a rotary hearth furnace. The aim is to learn from this installation and apply the concepts elsewhere in their many manufacturing operations.

2.2 Supply side characteristics

Since FMS represents a complex of different technologies, it is not surprising to find that the supply side picture is not very clear-cut. Although a few large firms do try and supply turnkey systems, the trend is increasingly towards combining different specialist products into a system-often involving an independent systems integration contractor. The main divisions in the supply industry are into the machining,handling and computer control elements.

As far as the machining elements are concerned this is still very much the province of the machine tool companies and there has been considerable diversification by major manufacturers into software development in an attempt to become suppliers of machine tool systems rather than stand-alone technology. Here the problem is that of product mix ; although large FMS can cost several million pounds,the potential market at present is small. In one UK study (17) interviews with machine tool suppliers suggested that around 80% of their business was in stand-alone equipment,with the majority of the remainder being small manufacturing cells with DNC links.

The nature of the problem on the supply side-and the type of response being made-is well illustrated in a recent paper from White Consolidated Industries,one of the main US suppliers of FMS and machine tools. (21). They point out that the process of solving a customer's manuacturing problems via FMS may simply shift them over to the supplier. In the case of an early FMS supplied to Ingersoll-Rand,for example,the customer requirement was to produce any combination of 127 different parts in a batch size of between 1 and 25 off. Machine utilisation was to be over 70% and the whole system manned by only 3 men/shift. WCI solved the problem by installing an FMS based on 6 machining centres of different configurations, a special purpose conveyor system and their own design of control system.

The difficulty this posed was that this was a complex and high cost product for WCI to produce ; their response was to opt for FMS technology within their own manufacturing operations and to seek to standardise on as many aspects of the product as possible. A survey revealed a potential standard part range which would meet 80% of user needs, and they used this size as the basis for design of a standard material handling system. This was followed by standard approaches to robot cells,fixturing,pallet transfer equipment and control systems; each of these has been subsequently developed but in essence the approach of the company has been to produce modules which can be fitted together to configure a system which is specific to customer requirements but general enough to be produced in economic volume by WCI. They see the advantages of this not only in terms of production economics but also in moving along the learning curve of FMS- a strategy which is being followed by many other firms. Significantly two of the earliest FMS installations in the UK were in machine tool companies whilst the Yamazaki example above clearly demonstrates the Japanese belief in the value of learning by doing.

As far as software and control systems developments are concerned,the pattern has been similar. Applications packages for individual functions-such as DNC,production scheduling,capacity planning,process routing and optimisation, MRP (materials requirements planning) etc are widely available as standard products. The major area of development is in integrating suites of software suitable for hierarchical control of FMS. It is important not to underestimate the costs of such software development; one spokesman for Kearney and Trecker, a major US supplier of FMS estimated that the costs of developing their present generation of software were about 130 man years. The nature of language and protocol incompatibility at present means that each FMS installation often requires a custom-written set of software which is costly and complex- a problem which is often compounded by the physical difficulties of laying the necessary physical links between different hardware elements. In the long term developments in operating systems (such as UNIX) and artificial intelligence may help reduce the software problem, and the use of local area networks and optoeletronic transmission is already having an impact on the linkage problem.

These difficulties are reflected in the present structure of the industry,with expertise concentrated in a few large software houses. Very few users -or machine tool suppliers- have sufficient in-house capabilitity to develop their own systems; using outside agencies does,however,pose some problems due to a lack of familiarity with the production processes involved.

On the handling side the picture is much less of a problem. As we have seen,there is a wide variety of choice of transport and handling system,ranging from robots through conveyors and AGVs to specialist pallet handling equipment. There does appear to be some concentration in this sector-with traditional material handling firms investing heavily in developments in automated storage and warehousing,for example- but there is still room for a variety of small specialist companies.

The same is true of other special purpose equipment-such as co-ordinate measurement machinery and other in-process inspection/measurement/monitoring machinery.

The problem posed for many users is the need to put together a system combining elements of many different technologies when their own experience is likely to be very limited. The result is that many are now delegating the task of selecting the best configurations to some form of managing agent whose role is to act as an independent integration contractor, specifying and managing the entire project much as has been the pattern in the large scale process plant industry for some time.

2.3 Government support for FMS

One last factor of importance on the supply side is the role which government has played in different countries in fostering the development and application of FMS technology. The arguments about the influence of advanced manufacturing technology on international competitiveness have been discussed elsewhere (22) and it is clear that the state is playing an increasingly strategic role in industrial policies concerned with AMT (advanced manufacturung technology). Implementation of these policies varies between countries but most involve a combination of direct financial support for investment-either in the form of grants or tax concessions, and indirect support via R and D programmes,public procurement or the wider infrastructure of education, training and public awareness media.

In the case of FMS there is growing state involvement although the subject is being attacked on a fairly broad front in most countries-reflecting its somewhat diverse nature and the problems of definition mentioned earlier. The Japanese have had a consistent policy since the early 1970s based around two major programmes- the MUM (Methodology for Unmanned Manufacturing) project which ran from 1972 to 1976 and the current ambitious 40m Flexible Manufacturing Systems Complex with Laser which is being developed at Tsukuba and should have been completed last year. As with much Japanese development there is extensive industrial participation and in the above project around 20 firms including Toyota, Kobe Steel, Makino, Toshiba and Toyoda have developed experimental units for demonstrating particular aspects of FMS technology. Significantly the Tsukuba R and D project is pushing FMS forward but also integrating different elements such as metal forming,laser applications,automated assembly,automated diagnosis and management software systems-in other words,producing an early blueprint for a full computer-integrated manufacturing facility. (23,24)

Beyond the R and D sphere Japanese support tends to be through the infrastructure via agencies like the Japan Development Bank with its preferential interest rates;this kind of support is valuable in the context of FMS where the high capital costs restrict the opportunities for achieving conventional payback characteristics. A development of some importance in this connection has been the MITI backed loan of about $5.6bn to Japan Robot Leasing at rates 0.4% below prime; JRL exists to help small and medium sized enterprises take advantage of FMS and related technologies (providing they are Japanese made) where they could not afford to buy them outright because of the payback problems.

In the USA state support has been largely through public procurement and major R and D contracts in the defence and aerospace field. Two major projects are of significance-the NASA IPAD (Integrated Programs for Aerospace Vehicle Design)- which deals many with CAD aspects and the USAFs ICAM (Integrated Computer-Aided Manufacturing) programme. The NASA project,worth around $10m and begun in 1975 is aimed at bridging the CAD/CAM gap,interfacing the design and manufacturing fields. ICAM is more ambitious; worth around $100m and started in 1977 it is concerned with various aspects of computer-integrated manufacturing including FMS development.

In this project-which is scheduled to run until 1987, the bulk of the work is being carried out on a contract basis and there are currently around 30 private companies, 20 universities and 5 private research institutes involved.

As with the Japanese programme, emphasis is being given to a broader future for FMS, embracing particularly the difficult area of sheet metal working. (14).

In the Federal Republic of Germany there has been recent concern about the issue of AMT and international competitiveness and this has led to a major increase in the level of state support with a total of $1.15bn being pushed into research for the next four year. The focus of this is advanced manufacturing technology with emphasis on robotics (DM30m), CAD (DM160m) and FMS; the expectation is that this money will be trebled by industrial contributions. This investment is in addition to a DM530m programme aimed at encouraging the application of AMT which was launched in 1984 and attracted over 700 applications in its first three months of operation. (25).

In the UK a number of schemes operate to support the development and take-up of AMT, with one scheme specifically earmarked for FMS. The main objectives of this scheme (which grew out of the Automated Small Batch Production Scheme ASP) were:

— To stimulate the development of a few large-scale schemes amongst larger firms whose products were amenable to production on FMS;

— To demonstrate FMS as a production engineering possibility to other potential users. One condition of a grant being awarded was that other companies should be allowed access to the installed system in order to assess the costs and benefits for themselves;

-- To encourage hands-on experience and experimentation and development of FMS options and technology

By January 1984 100 applications had been received and 35 of these were funded at the level of feasibility study. £10m was committed to projects and this figure had risen to £50m by the end of 1985; however,current government economies have placed a five month moratorium on all spending including the allocation of new projects.

In Eastern Europe and the USSR the role of government in directing and supporting technological change is much more one of direct intervention. Work was begun on computer-aided manufacturig in the early 1970s in the USSR and the German Democratic Republic, to be followed by Czechoslovakia and Hungary in the mid-1970s and Poland,Yugoslavia,Rumania and Bulgaria in the late 1970s. (14).

3.0 Benefits of using FMS

From the examples given in the preceding section it is clear that FMS in practice does appear to offer many benefits over conventional batch manufacturing techniques. Nor are these isolated examples; Annex 1 gives data on many FMS installations currently operating,from which it can be seen that reductions in work-in-progress,stock levels, lead times, direct labour costs and overall production costs and increases in quality and competitiveness have been regularly achieved. Table 3.1 indicates the results of a survey of around 80 FMSs in terms of the list of benefits regularly reported, and table 3.2 data on 7 US installations.

Table 3.1 Benefits of using FMS

- reduced unit costs
- better utilisation of capital equipment
- reduced material usage and lower levels of stocks and WIP, and in some cases, of tooling
- reduced lead times on new and modified designs, and changes to product mix
- improved product quality and step towards "zero defects"
- consistent level of output
- higher labour productivity
- reduced need for working unsocial hours
- easy to extend system to subsiduary operations
- easier shop floor production control
- reduced floor space, leading in some cases to smaller factories
- improved speed and quality of management information
- enhanced CAD/CAM linkage

(Source:NEDO (8))

Table 3.2 US experience of FMS benefits

Company %	a	b	c	d	e	f	g
Increased utilisation of machine tools	5-10	20	30	30	50	20	20
Reduced tooling inventory	50	-	-	20	-	-	-
Reduced lead times	20	30	40	50	35	10	-

(Source: Ingersoll Engineers, quoted in NEDO (8))

One important point which emerges frequently in discussion of FMS is that many of the benefits arise not so much from the technology itself as from the new ways of thinking about production organisation which FMS requires. Dempsey (26), for example, in reviewing the experience of around 39 FMS installations comments that "...on average 40% of the benefits predicted for an FMS are in fact achievable or have been achieved before the FMS is delivered and often within 6 months. This is because the planning process itself has highlighted existing custom and practice which is detrimental to cost and can be put right without major investment". In the same paper he describes an installation made in 1968 which achieved many of the benefits which would now be associated with FMS-yet this used conventional technology; the benefits arose because of the application of the philosophy of flexible manufacturing.

3.1 Diffusion factors

Given the impressive list of benefits above,it is somewhat surprising that FMS technology has not diffused more widely or rapidly. Closer analysis suggests a number of factors which help to account for this; these include costs, technological immaturity, lack of application potential, lack of skills and a variety of issues concerned with the integration of hardware,software and organisational systems.

As far as costs are concerned the picture at present is that FMS is very expensive,even taking its benefits into account. Average costs run into millions of pounds and in all but a very few cases the payback characteristics are much worse than for more conventional items of manufacturing technology. The diffusion problems associated with costs are not so much those of availability of capital as of attitudes towards investment. That is, in most Western economies there is less of a tradition of long-term strategic investment justification than in Japan-yet FMS needs to be seen in this longer-term perspective. It has been suggested that new approaches to investment justification are needed to take account of the long term benefits which FMS offers,rather than applying conventional approaches only. As one commentator put it, " reductions of WIP and inventory should be assessed for initial savings and for long term reduction of overheads. Second the effect of the payback period should be looked at and worked out on the basis of both a 1-2 shift level of production-which could be the same as current production levels- and a 2-3 shift basis. Associated with this, the effect of single,double and treble shifts on component unit costs should be worked out-as should the possible effect on market share levels due to reduced production costs " (27) . To confirm this last point,the Yamazaki installation at Oguchi paid for itself within two years and much of this was attributed to the fact that overall business performance improved significantly- in part due to the reduced lead times and costs contributed by the FMS element in the machine tool production process.

One last point which should be raised in this connection is the potential which FMS has for capital-savings. Although costly there are two areas in which this investment may be recouped; in replacement of many old machines by a few integrated new ones and by reducing the amount of capital tied up in stocks and inefficiently used space. The effect of all of these factors has been to put pressure on organisational accounting methods to adapt and accommodate the challenge posed by major technologies like FMS.

Technological immaturity refers to the fact that in most cases the present generations of FMS are being used as much for learning and demonstration purposes as for production. Both users and suppliers recognise that the systems of the future are likely to be more flexible, modular in design and able to handle a much wider range of parts at lower overall cost. Many-like Kearney and Trecker (28) consider there to be at least three generations of FMS already-the first,built in the early 1970s involved flexible transfer line type systems with low parts variety and relatively high volumes. The second -more of a real FMS-involved greater flexiblity but in order to achieve this most users had to go for an expensive greenfield site option. Only now are they beginning to standardise to the point where costs fall and applicability rises.

Despite these problems on the supply side, the real lack of technological maturity is on the user side. Although the costs of FMS have tended to exclude all but large firms, evidence suggests that awareness of its potential applicability-particularly of smaller configurations such as FM cells- is relatively poor.

Many of the problems on a technological level relate to systems integration; the pattern of development has largely been confined to discrete elements in the manufacturing process and it is only now that many of the issues involved in putting systems together are being confronted. For example,in the software area it should in theory be possible to make use of common databases and network communications to support FMS control. In practice there are a number of compatibility issues which must be resolved,including the urgent need for standardisation of languages,operating systems and protocols-quite apart from the high development costs involved.

Another problem area is in sensor technology; as systems move towards high levels of integration, so it becomes critical to detect changes in operating conditions and correct for them. Tool wear is a typical example of this where extensive work is still needed on monitoring and detection systems before full automation of tool management is possible. For this reason firms are no longer looking at the option of totally-unmanned operation but are beginning to build into their systems design a role for skilled operators/supervisors- recognising that flexibility can be enhanced through this approach. Other strategies to cope include the Yamazaki method of running tools at less-than optimum cutting speeds to reduce wear and increase continuity.

Although FMS is often thought of as a labour displacing technology,one of the main factors limiting its diffusion is in fact a shortage of key personnel. The main requirements appear to be at high levels,particularly manufacturing systems engineers who are able to combine production engineering and software skills-and who have some understanding of the plant and products involved. Other skills in short supply include technicians and maintenance personnel to support highly automated FMS installations.

There is no evidence of any direct opposition to the introduction of FMS from trade unions but many commentators point out that this type of technology actually poses a greater threat to middle management who are in a powerful position to block change by exerting control over key information. How far this is a problem is difficult to predict but at present it has not really been a significant factor.

The major organisational problems concern adaptation to FMS-getting the best fit between the technology and the existing pattern of work organisation. Early evidence seems to support the view that there is no single "best" way of doing this but rather that, much as the technological configuration varies between firms, it is a matter of finding the most appropriate solution for a given context. Reports of mismatches (29) do stress ,however, that flexible manufacturing needs a considerably more flexible organisation-in terms of working practices, skill distribution and work organisation.

As mentioned earlier, many of the benefits of FMS come from applying the principles of this approach to manufacturing rather than the technology itself. For this reason it is suggested that much of the problem in organisational adaptation arises because of the need to learn new approaches to planning and implementation of technology and to production management as a whole. This may help to explain the relative success in Japan of using FMS since the approach to production management-based on simplicity in design of product and manufacturing process-is much more in line with the philosophy of FMS.

4.0 Employment issues

At first sight FMS appears to pose a major threat to employment because it implies that fewer people will be needed to run such automated systems and those who remain will be deskilled to the point where their main contribution is in machine minding and loading/unloading tasks. Although there is some evidence of labour displacement in many FMS installations the employment implications are complex and not all negative.

First it must be said that the massive labour displacement which might have been expected on a straightforward substitution of FMS for conventional technology basis has not occurred. Reasons for this include:

Many projects are of the "greenfield site" variety and have no effect on existing labour levels; some even recruit new staff;

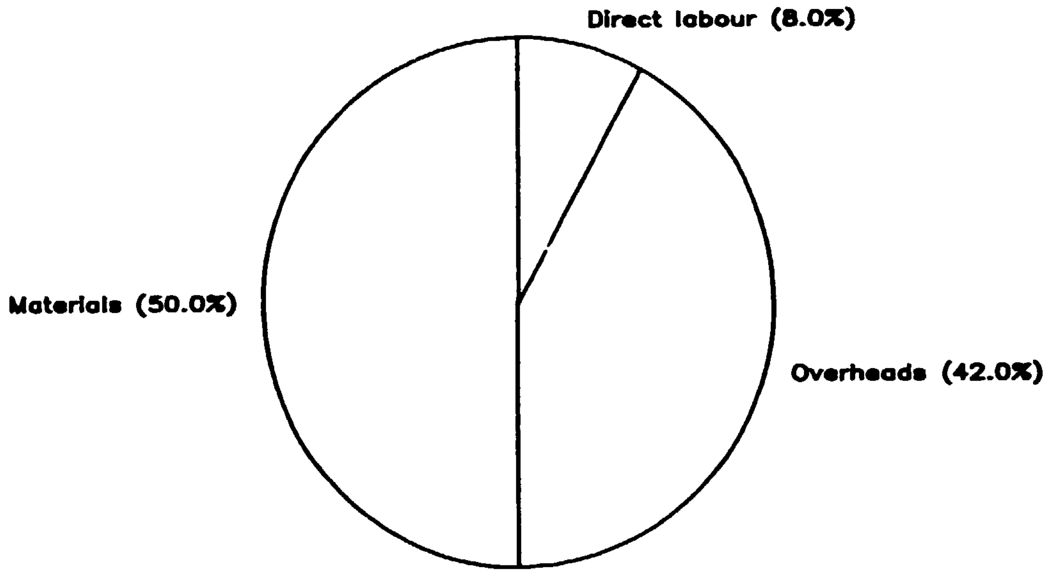
Diffusion of the technology is still at an early stage and many firms are in the learning stages and are unwilling to implement systems to their full labour-displacing potential yet;

Many firms shed labour during the 1980 recession and are now using FMS as an alternative to re-employing many workers displaced then rather than displacing current staff.

A significant point is also that many firms are now beginning to realise that the cost structure of industry no longer has direct labour as its major component. As figure 4.1 shows, the main areas of difficulty are in overheads and materials and there is a subsequent shift towards investing in technologies which attack these problems rather than which save labour directly.

Figure 4.1 Cost breakdown in UK manufacturing industry

(Source: Small (30))



Although much of the stimulus for FMS development came in the enthusiasm of the mid-1970s for "unmanned manufacturing", most firms have now retreated from this idea to one in which there is minimum manning and the possibility of an unmanned night shift. The Japanese experience is probably the most developed along these lines where a rough ratio of 10 to 1 is the order of labour reduction between conventional and FMS technology and where systems are left with sufficient pallets of work to run an unmanned night shift under supervision of a small team looking after the entire plant. (12). However, some commentators point out that even in these cases the actual direct operators are supported by many ancillary workers; in the Yamazaki installation at Oguchi,for example, Driscoll (19) found that the six direct operators were backed by perhaps ten times as many looking after various tasks such as swarf removal,loading/unloading,programming and other white collar jobs.

The claims for unmanned manufacturing during the night shift also need reinterpretation; in most instances this really means that the plant has the potential to run unmanned for short periods if needed. In one survey (17) of Japanese installations around half (14 out of 29) prismatic component FMSs and one out of nine rotational part systems were running on an unmanned night shift basis.

Although there are similar job displacement figures for Europe and the USA, (see Annex 1), it must be said that the evidence for job displacement due to FMS is not yet strong. Much depends, as Kohler <u>et al</u> (31) point out, on the choice of implementation strategy adopted by the organisation. Various research projects (eg Kemp et al

(32), Rosenbrock (33)) have identified a wide range of potential choice in the way in which work is organised and skills distributed around FMSs.

In terms of skills requirements most user firms report an increase in demand for certain types-programming and maintenance being by far the most important. For the latter,research in the Federal Republic of Germany on the Messerschmidt-Bolkow-Blohm FMS at Augsburg indicated how far the shift in importance from direct operation to indirect support ,particularly maintenance-has gone. Here the entire system is designed for high utilisation so that any stoppage is extremely costly; emphasis in maintenance has been to try and get condition monitoring on the plant and to increase the amount of preventive maintenance which can be carried out between shifts.

Nevertheless, the system does break down and their analysis of downtime costs over a 6000 hour period for 24 machines working on a 3 shift basis was as follows:

-56% maintenance and repair
-13% routine maintenance and inspection
-17% facility improvement
-14% non-technical downtime

Of the 56% maintenance time the distribution was as follows:

-22% reaction time
-20% diagnostic
-9% replacement parts supply
-40% repair/overhaul
-9% resumption of operations

This places the burden of downtime very much on the shoulders of maintenance personnel; the conclusions from the study were that the length of breakdown time depends on three factors:

-intensity of machine utilisation

-degree of monitoring and facility improvement

-skill levels and qualifications of the maintenance personnel

Their overall conclusion was that "...the more complex and automated the systems were, the higher the skill levels of maintenance specialists had to be to achieve reasonable failure rates and implement facility improvements .....and...the lower the personnel levels were (production with automated facilities) the broader the educational background of these workers (operators and maintenance) had to be" (34).

Thus FMS, at this stage in its development, must be seen as a technology which has considerable labour displacing potential although this has not yet been realised in practice, and which has both skill saving and skills intensive characteristics.

5.0 Wider issues

From the foregoing it is clear that FMS, whilst still relatively immature, offers significant benefits in batch manufacturing. At the same time it poses a number of challenges to traditional practices and structures in the organisation and management of production. As we noted earlier, FMS is as much a philosophy of production management as it is a technology - and the successful implementation of FMS appears to require new ways of thinking about production. Components of this include :

-design for manufacture

-integration with sales and marketing

-a longer term, strategic view of investment justification

-greater emphasis on indirect support activities,particularly maintenance

-responsibility for quality throughout the manufacturing process, not just at a late inspection stage

-a planned implementation strategy- even when the system is being built up in incremental modules- towards a clearly defined long-term goal

-appropriate matching of system to the user's needs and internal resources

-an overall simplification of the production process in terms of operations and flows of materials and workpieces.

Experience so far has been in large firms, but the pattern is increasingly coming to favour small/medium sized firms with the development of flexible machining cells. As we noted earlier, the number of large firms with product ranges and values suitable for FMS or FTL is fairly limited; the major market for machinery suppliers is in the smaller range of stand-alone machine tools. Many firms are now recognising the possibilities of developing their own flexible systems based around CNC stand-alone tools but supported by computer-aided production management , quality management, CAD, etc. The point made earlier is valid here; that most of the benefits to be gained from FMS are independent of the technology itself and come from a reappraisal of manufacturing systems. It can be argued that smaller firms-with their greater organisational flexibility- are in a strong position to exploit such "flexibility in manufacturing systems.

A case in point concerns the subcontracting industry serving the aerospace sector in the UK. In recent research (17) a number of firms were interviewed about their future prospects ,given that British Aerospace were making the largest investment in the UK in flexible manufacturing systems in order to be able to make small batches in-house rather than putting them out to contract. The majority of firms were quite sanguine about their prospects, pointing out that their internal flexibility- what they termed "being quick on their feet"- allied to efficient use of skilled and experienced men working on advanced CNC stand-alone equipment had so far helped them to achieve lead times and qualities comparable or better than the large-scale FMSs in operation elsewhere. These were all small firms,employing between 20 and 60 people and batch sizes were very small-often one-off prototype developments or repairs.

In many cases attempts are being made to build up to full FMS via a series of modules, thus spreading the high investment cost over several increments. Such an approach might begin as above with a cell based on CNC stand-alones; the next step might be to add some form of automated handling or scheduling. Later links could be made to transportation and stock control or to overall DNC- and so on. The advantages for smaller firms lie in both lower cost and a gradual learning and acquisition of experience about flexible manufacturing. However, such an approach needs a clear sense and plan of where the process is leading; unless individual investments are made in the light of an overall picture with due consideration being given to issues like compatibility and software standards, the result may be an inflexible and inefficient system. A number of large firms have already experienced this difficulty because their strategies of acquiring advanced technology during the 1970s were essentially unintegrated, being the responsibility of different departments. Now that they are trying to develop FMS and CIM, they are finding that the problems of compatibility are more costly to solve than scrapping their investments and beginning again from scratch.

For many commentators FMS is opening up a new line of debate about production economics concerned with what have been termed "economies of scope". In essence the argument is that the ability of FMS to produce small batches rapidly and efficiently undermines the traditional advantages of scale economy and makes it possible for small to become beautiful-or at least economically viable. Whilst full FMS configurations are expensive, there is a growing range of lower-cost FMC technology emerging which may be suitable for smaller firms; additionally,flexible manufacturing technology can contribute considerable capital savings through integration of machine functions and reductions in inventory.

That it is possible for small systems to produce competitively is becoming clear; what is less obvious is whether this will reinforce the strength of large firms who will use FMS to operate smaller plants and attack new markets usually served by smaller,local firms- or whether those smaller firms can strengthen and even advance their position through the use of the technology.

One important development in this respect is the closer integration between suppliers and customers in the manufacturing chain which FMS and related developments fosters. Although one option might be to use FMS to bring all production of previously bought-in components in house, another would be to help sub-contractors obtain the benefits of FMS some of which could be passed on in the form of lower or stable prices ,improved quality,shortened lead times,etc. This depends on the sub-contractor being able to justify the high costs of investment in FMS- something which can be done if the terms of contract with the customer firm move away from the traditional confrontation over price and towards a long-term relationship of mutual co-operation. This latter model is increasingly to be found in Japan and many European and US firms are also implementing it since it offers benefits to both sides in terms of stability and reliability. (35).

For developing countries there may be some important lessons. First it is clearly a matter of some urgency that FMS developments should be explored since one of the consequences of this improved competitiveness is a reduction in comparative advantages based on cheap labour costs. This will be dramatically the case when flexible assembly technology arrives since this may make possible the often-threatened relocation of assembly operations of transnational corporations back in the developed countries.

Second, and potentially more significant, is the possible use of these systems to achieve a stronger competitive position in world trade. Whilst full FMS with its high cost and skills requirement may be inappropriate, variants on the FM cell concept-which may be adapted to suit local conditions- could be implemented to improve the pattern and economics of small batch manufacture. Many commentators have pointed out in the developed countries that there is a wide range of choice associated with the way in which CNC machine tools can be used-ranging from configurations which make maximum use of skills where these are present to those in which the required skill component is embodied in the control software and the only direct operation required is in loading/unloading and tool/workpiece setting.

Low cost machining centres-such as the Tsugami Matchmaker which the manufacturers actually term a "flexible manufacturing system"- could provide the basis for such cells. Since it appears that the main benefits are not technology but people/management skills intensive, there may be options open for low cost entry into FMS for some developing countries. The experience of Japan in developing alternative approaches to production management illustrates clearly that much can be achieved through a gradual but persistent attack on problem areas - and that solutions to these problems do not need to involve expensive technology. The KANBAN system of production scheduling and materials procurement developed in the Toyota plant has often been put forward as a model which Western firms wish to emulate because of the benefits which it provides in inventory reductions and production efficiency. Yet, as Schonberger (12) points out, this began life as a simple paper-based system without a computer in sight!

In the newly-industrialising countries, the possible implementation of full FMS or even FTL configurations could be considered since there is less of an established traditional industrial infrastructure to replace. Some commentators have suggested that the NICs may be in a strong position to "leap-frog" the developed countries because of this lower level of commitment to existing technology-and FMS seems a prime candidate for such a move.

6.0 Conclusions

This report has tried to outline briefly the current state of development and the likely future prospects in the field of flexible manufacturing systems. It has indicated that FMS is not so much a technology as an approach to production of small and varied batches which has a high potential applicability in a number of industrial sectors. Although still immature flexible manufacturing appears to be developing along a broad front running from flexible transfer lines suited to large firms with high volume low variety production, through medium volume/variety work on flexible manufacturing systems to high variety, low volume work in flexible manufacturing cells.

This last group has probably the widest appeal since it is relatively lower in cost and matches the parts profile of the majority of manufacturing firms; around 70% of all products are made in batches of 50 or less.

The implications of FMS technology for the pattern of world trade in manufacturing are hard to assess.

Potentially it offers to revolutionise small batch manufacturing economics, making use of the economies of scope implicit in the technology. This has yet to happen in practice because of the slow diffusion of FMS and the relative immaturity of the technology and the users. Nevertheless, the benefits so far achieved by early users suggest that there will be an increasingly rapid take-up of the technology in the advanced industrialised countries. Although at present largely confined to metal cutting activities, the direction of current research indicates that the concept of flexible manufacturing is likely to be applied in all batch-based industries- castings, forgings, plastics,rubber, clothing and footwear etc. By far the most important development in this context will be flexible assembly technology-and evidence suggests that this is already highly developed in sectors like electronics, instruments and consumer products.

In view of this imminent shift in the pattern of batch production, it is a matter of some urgency that developing and industrialising countries explore flexible manufacturing and assembly in greater depth. Although the above indicates its role as a threat because of its likely erosion of competitive advantages based on low labour costs, the nature of the technology itself may provide an opportunity for entry into flexible manufacturing- at least at the level of flexible manufacturing cells.

Above all it is important to recognise that flexible manufacturing is as much about alternative ways of thinking about and organising production as about sophisticated and expensive technology.

Data on FMS Installations

	Country	Company/ industry	Configuration	Cost	Batch size	Product range	Shifts	Labour impacts	Inventory	Lead times	Other benefits
<1>	France	Citroen Cylinder heads,clutch housings,gear box cases	2 machining centres 1 co-ordinate measuring machine Auto tool management Auto swarf conveyor AGV transport Pallet-based	35.5m francs	15 (min)	Prismatic	3	Uses 33 instead of 73 in a normal plant			Cheaper than conventional lines 35.5m vs 39m. Later lines will be cheaper-about 29m francs,due to learning effects.
<2>	UK	600 Group (SCAMP) Machine tool components	10 machine tools Conveyor transport Robot handling and tool change	£3m (some govt. support)		Rotational 46 diff. parts	1 at present				
<3>	UK	Aerospace	10 machining centres 2 special purpose Automatic inspection Automated stores AGV transport Auto tool management Fibre optic LAN communications	£10m 7-10 yrs payback (depends on govt. grant)	Small	Prismatic 100 diff.	3			Cut - 16 wks to 3	
<4>	UK	Electronics	9 special purpose Automated test Robot handling Robot insertion AGV transport	£2.5m 2.5 yrs payback	80,000 per year	220 boards and 3500 components		Less than current level-55		3-4 wks to 6-8 hours	Main motive was to reduce the complexity-potential 5m different combinations of boards and components
<5>	UK	Engines	2 special purpose 1 CMM Auto handling Later CAD links	£800,000 2 year payback	100 off (max)	1to 17 Cylinder heads/ engine sets	2 (3 later)	Labour + equivalent initially per year	WIP saving to £200,000 and £300,000 afterwards		
<6>	UK	Engines	7 Machining centres 2 special purpose Tool magazines Special purpose fixturing	£4.5m	Large	Small-prismatic Crankcases	2	about 90% reduction (direct/ indirect)	93.5% reduction expected		
<7>	West Germany	Zeiss precision components	4 machining centres 1 CMM Auto pallet handling AGV transport	5 yrs payback (on 2 shifts)	10 to 1000	150-mainly aluminium housings Prismatic	2 (3 later)	70% saving		Door-door time 6 wks - 4 days	Setting time cut by 80% Tool costs cut by 50% through standardisation of tools and fixtures Transport costs cut by 80%

<8>	USA	Caterpillar Main base frames for earth movers	4 machining centres Special purpose line Pallet/AGV feed 3 level DNC		430/mth	4 large prismatic	2 (3 later)	Total needs 2.3 men/shift			Less than 7% downtime Spare capacity will enable a fifth frame to be added to product range handled
<9>	USA	John Deere Tractor clutch and transmission housings	12 (later 16) large machining centres AGV transport Headchanging machines Tool management	$16m ($21m for full system)	Large	9 large prismatic	3	Some savings			Setting times dramatically reduced. Shorter design cycle means greater product flexibility
<10>	West Germany	ZahnradFabrik (ZF Gears)	13 manufacturing cell 7 machining centres 14 robots Overhead crane transport	£6m with 30% govt. grant	16,000/month	4 families 350 diff. gears Prismatic 12 basic parts	2	30% cut			Productivity up 40% on 2-shift operation and 70% on three compared with conventional plants
<11>	USA	General Electric Erie (electric motor frames)	9 machining centres AGV transport	$16m	5600/yr	Family of 7 variants Prismatic	2	16 men for 2 shifts vs 86 for old plant		16 hrs against 16 days on old plant	Estimated increase in productivity over old plant of 240%
<12>	Japan	Fanuc (machine tools)	30 machining centres Robot load/unload	$32m		Prismatic	3	Estimated 90% saving over trad. plants.			Estimated five times more productive than conventional plants.
<13>	Hungary	CSEPEL (machine tools)	4 machining centres 1 CMM 1 robot Pallet conveyor	£4m		17 diff. Prismatic					
<14>	UK	Automotive component producer	FTL comprising 4 lines of special purpose machines Conveyor transport Supervisory DNC Integrated casting facility Robot transfer	£12m 3 to 4 years payback	8000/wk per line	20 plus variants Rotational	2	Cut by 60% Now uses 4 men/line vs 18 on old lines		Setting times cut from 24 to 1 hour	
<15>	USA	Vought (aerospace)	8 machining centres AGV transport Pallet handling	$10m		2000 Prismatic		Uses 5 men instead of 58 on old plants	Cut by 90%		Labour costs per part cut by 90% Utilisation estimated at 90%
<16>	France	Renault (gearboxes)	7 machining centres 8 robots AGV transport	£3.75m	70/day	4 (cast iron and aluminium) Prismatic	3	Uses 15 men (5 per shift) for whole plant			Tooling change cut from 80 hours to 4
<17>	West Germany	Deckel (machine tools)	8 machining centres AGV transport Pallet handling		2000/yr	28 diff. Prismatic	2		Cut by 50%	Cut by 33%	Drastically reduced batch sizes

<18>	West Germany	Deckel (gear housings)	FTL based on 6 special purpose machines		70,000 per year	4 diff. Prismatic	2	Minimum			Improved flexibility and constant throughput
<19>	France	Alsthom-Unelec (electric motors)	3 machining centres AGV transport Pallet handling		7000/yr	4 families 12 parts	3	Original line had 40 men FMS can run with 1 operator per line			Replaced 15 machines with 2. Also able to add a third shift.
<20>	UK	Anderson-Strathclyde (mining equipment)	6 machining centres AGV transport	£6.5m		Prismatic					
<21>	West Germany	MBB (aerospace)	28 machining centres Conveyor transport Automated tool mgt. Automatic chip disposal	$50m	Small (plant makes 10 planes/month)	Prismatic Light alloy Ti,Al,etc	3 later 2 9 hr	Cut by 44%		18 mths vs 30	Reduced no. of machines req'd by 40%, floor space by 39%, time by 25%
<23>	Belgium	Caterpillar (engine frames)	4 machining centres 1 special purpose AGV transport	25,000DM	Small	Prismatic 4 parts	2 later 3				60% utilisation 95% uptime on machines
<24>	UK	Caterpillar (gearbox parts)	4 machining centres AGV transport	£1.5m	Small	Prismatic 9 parts	2 later 3	2 operator per shift			
<25>	UK	Cessna Fluid Power (hydraulic pumps)	3 machining centres 1 CMM 2 robots	£1m (incl govt grant)	Small	Prismatic 2 basic pumps Up to 200 variants	1 plus 4 hours (auto) later 2	1 operator per shift			
<26>	UK	Valve equipment	4 machining centres AGV transport Automated tool mgt.	£2.4m (incl. govt. grant) Payback 2.7yrs	25to 150	Prismatic		£220,000 per year	£25,000/yr		Savings on reduced scrap =£50,000/yr Savings on overheads =£130,000/yr

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