Flexible manufacturing systems and cells in the scope of new production systems in Germany: final report

FLEXIBLE MANUFACTURING SYSTEMS AND CELLS
IN THE SCOPE OF NEW PRODUCTION SYSTEMS
IN GERMANY

Final report of the German part of the projects commissioned by the Commission of the European Communities

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INTRODUCTION

The rapid development of micro-electronics and the associated development of the information technologies is bringing about changes in an increasing number of fields of application. Thus, in the field of industrial production, we can expect to see fundamental changes of structure on the basis of the new technologies, such as computer-aided-design (CAD) and manufacturing (CAM), together with the interlinking of these functions in the next few decades. These ideas are currently being discussed extensively under the heading of 'The factory of the future' or 'The factory of 2000'.

The effects of these technologies on profitability, work organization, work qualification and vocational training, together with the forms they can be given and alternative concepts are - especially in international comparisons - still largely undetermined. Various lines of technical/organizational development in these new technologies are beginning to emerge. Alternative effects of these systems can be expected.

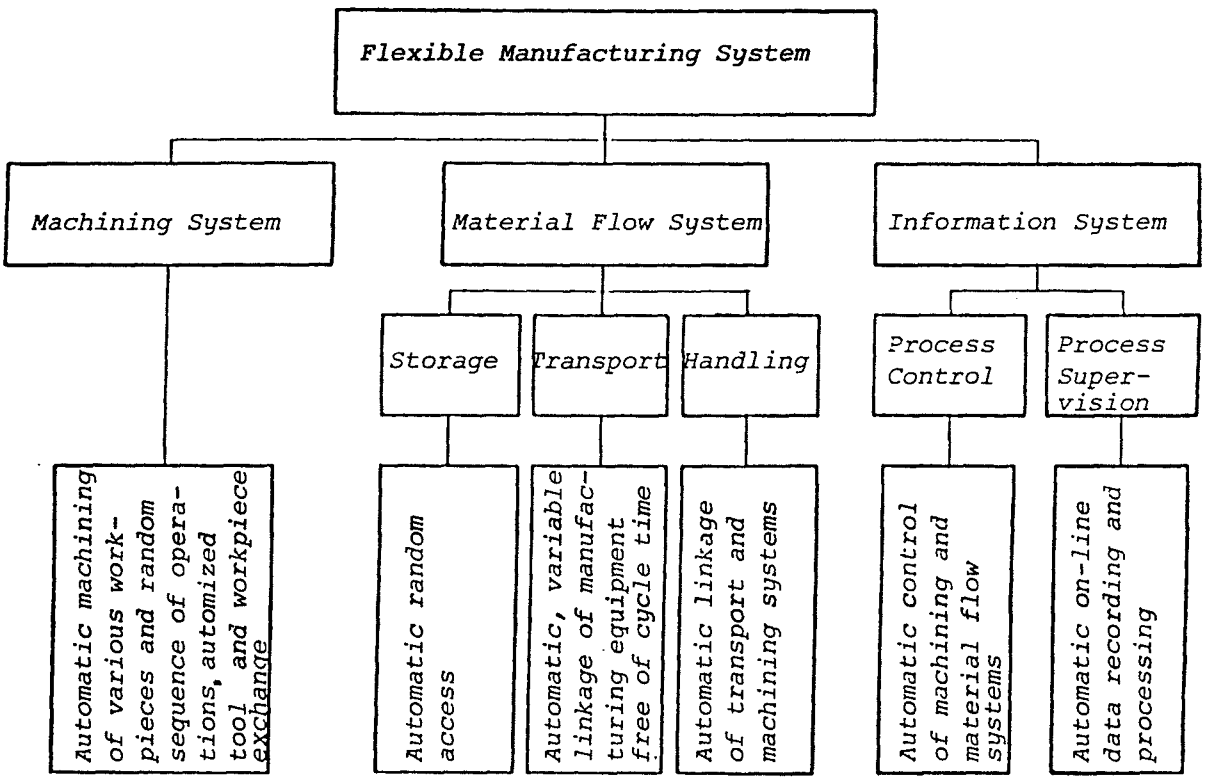
This is the background against which the Fraunhofer Institut für Systemtechnik und Innovationsforschung (ISI) and the Institut für sozialwissenschaftliche Forschung (ISF) were commissioned by the Commission of the European Communities and additionally supported by the Ministry for Research and Technology of the Federal Republic of Germany to draw up an examination also to be used for an international comparison of the dissemination and the economic and social effects of flexible manufacturing systems as an example of new technologies.

The concept of 'Flexible Manufacturing Systems' was introduced in 1967. The term was understood to cover a series of manufacturing devices interlinked by a common control and transport system in such a way that it was possible, on the one hand, to achieve automatic manufacturing and, on the other hand, to carry out various processing tasks on different workpieces within a given area (Dolezalek/Ropohl, 1970).

Since it is not possible in the short term because of technological and economic problems to completely meet the requirement of automating the components of the system, the definition given must be interpreted as constituting an objective, which is achieved to different degrees by the utilization of flexible automation systems.

Consequently, the present investigation is based on a definition which comprises both flexible manufacturing systems in the full sense of the term, i.e. multi-machine systems, as well as flexible manufacturing cells (single-machine systems). The components and structures are illustrated in Figures 1 and 2.

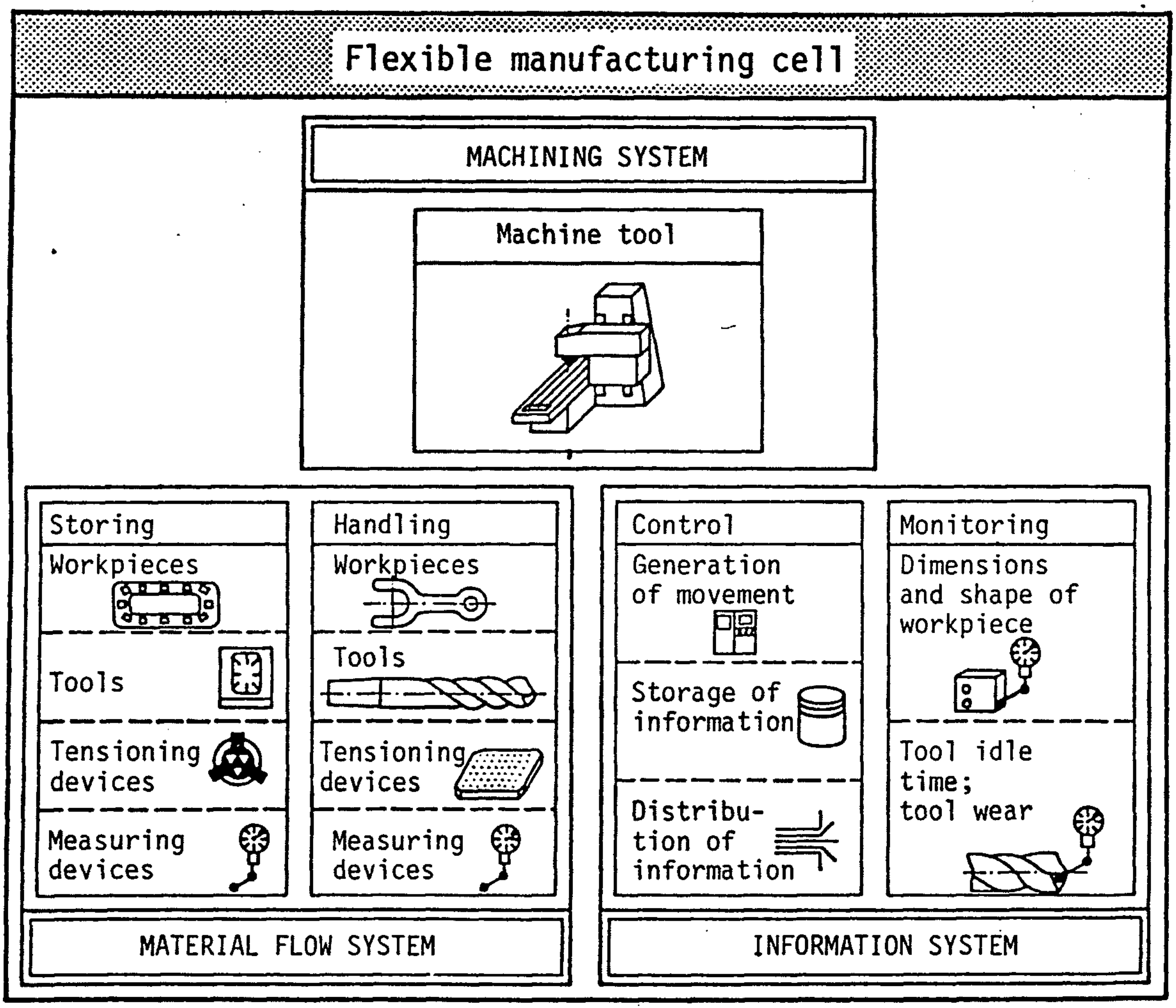
Figure 1: <u>Technical Structure and Features of Flexible Manufacturing Systems</u>



Within the framework of the task description given above, we carried out in autumn 1985 a written enquiry into the current state of the utilization of flexible manufacturing systems and cells in the Federal Republic of Germany the results of which are presented in part I of this report. This enquiry concentrated on the metal cutting branch, since this type of manufacturing process can be considered as a pilot sector for the utilization of FMS.

This written enquiry has been augmented and substantiated by case studies of companies operating FMS. These case studies are presented in part II of this report.

Figure 2: Components of Flexible Manufacturing Cells



I. STATE AND TRENDS IN DEVELOPMENT OF FLEXIBLE MANUFACTURING SYSTEMS AND CELLS IN THE FEDERAL REPUBLIC OF GERMANY

1. Type and Extent of Utilization of Flexible Manufacturing Systems and Cells (FMS/FMC)

1.1 Present Dissemination

Intensive examination of technical literature and references given by machine tool manufacturers showed that in autumn 1985 there were 278 FMS/FMC installations in 144 firms in the Federal Republic of Germany. Of these, 195 were flexible manufacturing cells and 83 multi-machine systems.

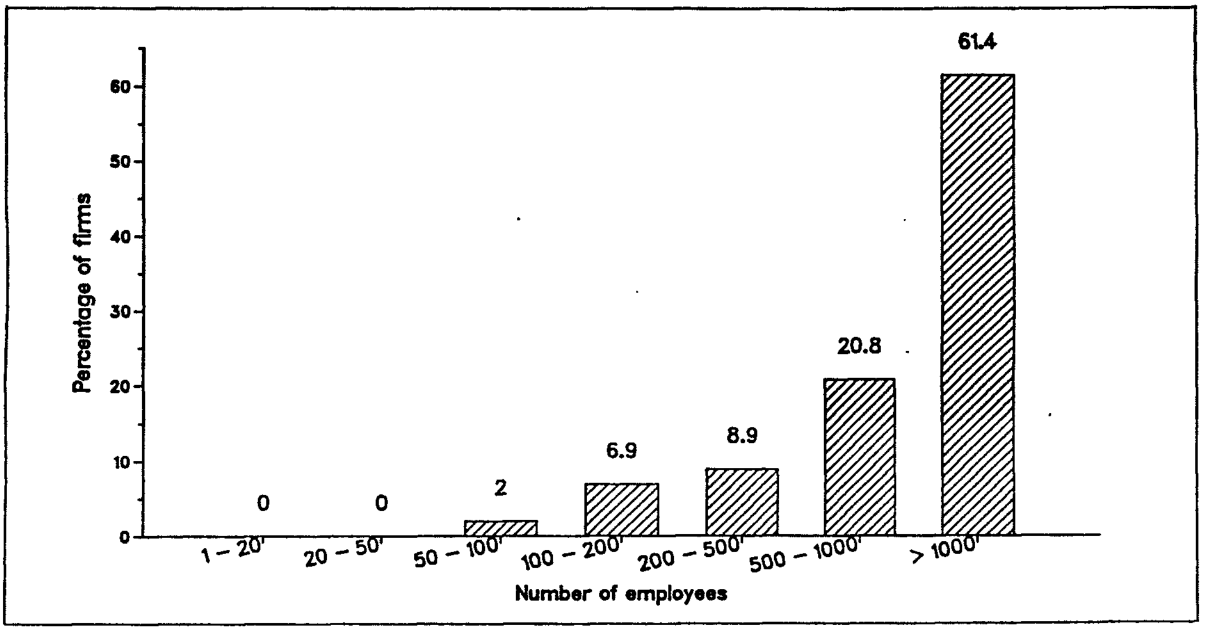
The companies concerned were predominantly (68,9 %) in the machine building industry. Other sectors, which were less strongly represented, are automobile industry (8,4 %), aircraft and aerospace (3,4 %), electrical equipment (5,9 %), precision engineering and optical industry (3,4 %) and iron, lead and tin products (3,4 %).

An analysis of the firms according to the number of employees (figure 3) clearly shows that utilization occurs particularly in fairly large organizations with more than 1000 employees (over 60 % of the installations), and shows generally that there is increasingly frequent utilization with an increase in company size.

Consequently, flexible manufacturing systems and cells currently constitute a technology which is of little significance for the large majority of small and medium-sized companies.

The distribution by system size of the flexible manufacturing systems and cells in service is given in figure 4. The great majority of the installations are flexible manufacturing cells (70,1 %). The categories of two-machine and three-to-five-machine systems represent approximately equal shares (11 %) while large-scale systems (more than five machines) constitute only 7 % of the total. This distribution is in striking contrast to the distribution of system size recorded in an early phase of FMS/FMC deployment: at that time, over 70 % of the FMS were large-scale systems (compare FhG-ISI/IAB/IWF, 1981). Thus in the meantime there is a definite trend towards the use of flexible manufacturing cells and smaller systems comprising up to five machines.

Figure 3: Analysis by Number of Employees

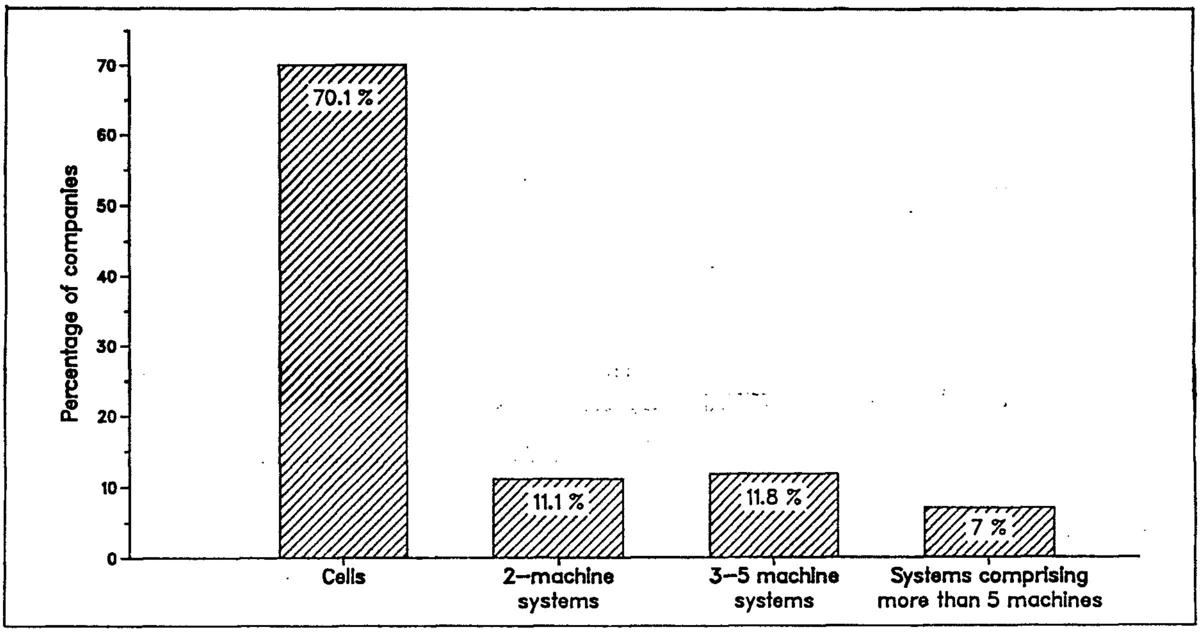


Analysis of the sizes of system installed in relation to the size of the organization (number of employees) shows that the number of large enterprises (more than 1000 employees) in the total number of user companies falls off as the size of the system decreases. The large-scale enterprises - with systems having more than five machines - represent a share of almost 90 %, while those with cell installations total only 56 %. The more frequent installation of cells and smaller systems is thus closely associated with the increasing confrontation of small and medium-sized companies with flexible manufacturing technology.

With this overall picture of FMS/FMC installations in the Federal Republic of Germany is a background, the above-mentioned written questionnaire gave us certain details concerning 93 installations: 35 flexible manufacturing cells, 22 two-machine systems, 21 systems comprising 3 to 5 machines and 15 systems with more than 5 machines.

Comparison of the user firms for these 93 installations with the totality of users of FMS/FMC in the Federal Republic on the basis of the manufacturing sector and the size of the firm (number of employees) showed no significant differences in sectoral distribution; on the basis of the distribution of firm size, smaller companies with fewer than 200 employees are somewhat under-represented.

Figure 4: Distribution of System Size



More marked deviations occurred in the comparison of distribution of system size. Whereas with multi-machine systems some 70 % of all groups were covered by the written questionnaire, the proportion of cells was only 18 %. This deviation is due to two principal reasons:

- As was shown by the comparison of the firm size classes, answers were received less frequently from the smaller firms. However, smaller companies had principally installed only flexible manufacturing cells.

- Relatively large firms with several installations often filled in the questionnaire only in respect of their larger (i.e. multi-machine) installations and gave no information about the cells they had installed.

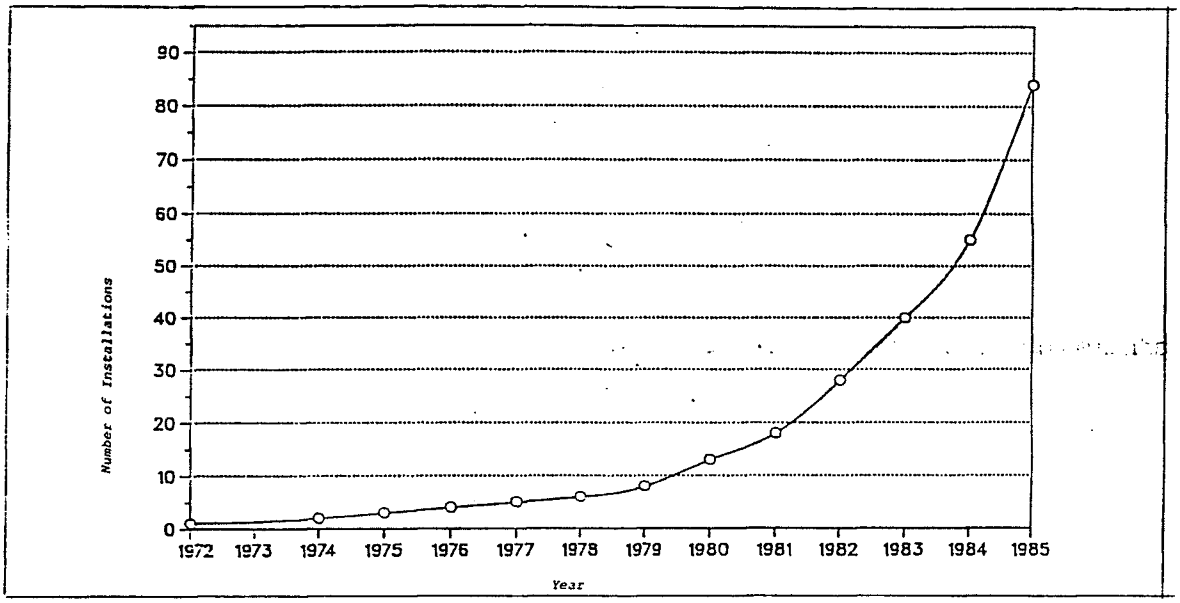
The result is that in the following quantitative assessments the data broken down by system size are representative, whereas average values for all installations are distorted by the differing responses given. These data must therefore not be considered as absolute values, if significant deviations do arise between the individual system size categories.

1.2 Developmental Trends

If we analyse the FMS/FMC in service in Federal German companies from which information was obtained by the questionnaire according to the year of installation, it will be seen that the first utilization dated roughly from the year 1972. This first installation was an FMS used to manufacture large parts for printing machines in a system of ten interlinked machine tools. In other countries, too, FMS were first used in the early 1970s; up to around 1980 deployment was slow. In 1980, the number first reached 14; Warnecke (1985) speaks of 25 systems in service in 1983. This was due partly to the poor market availability of FMS. The first flexible manufacturing systems installed were built according to specific operational requirements of each particular user firm, and these conditions were normally not reproducible. A further hindrance to rapid introduction of FMS/FMC was the heavy expenditure in time and money for planning and introduction which resulted from the lack of existing examples. The high risk attaching to these investments frightened off many potential users of FMS in the early years. The slow distribution of flexible manufacturing systems during the 1970s is also attributable to the system philosophy existing at that time: there was a preference for large-scale FMS (with more than five interlinked machines), with a view to achieving the 'manless' factory by means of these automated systems. From 1980 onwards dissemination of the systems speeded up and in 1984 and 1985 the total number had reached twice the figure for 1983 (see figure 5).

A further encouragement of the use of FMS/FMC was the change which occurred in the required level of investment. All in all, standardization of the planning process and of the system components brought about considerable reductions in the investment costs required per interlinked machine. In addition, it became clear that the proportion of investment required for processing and material flow systems had shifted. Whereas in the early stages of FMS deployment some 30 % of the costs were required for the materials flow system - which is not truly a productive system - this proportion had meanwhile fallen to some 20 % and the economics of the overall system had consequently improved. Nevertheless, there are still considerable difficulties in demonstrating the economic advantages of an FMS/FMC using the conventional methods of profitability calculation.

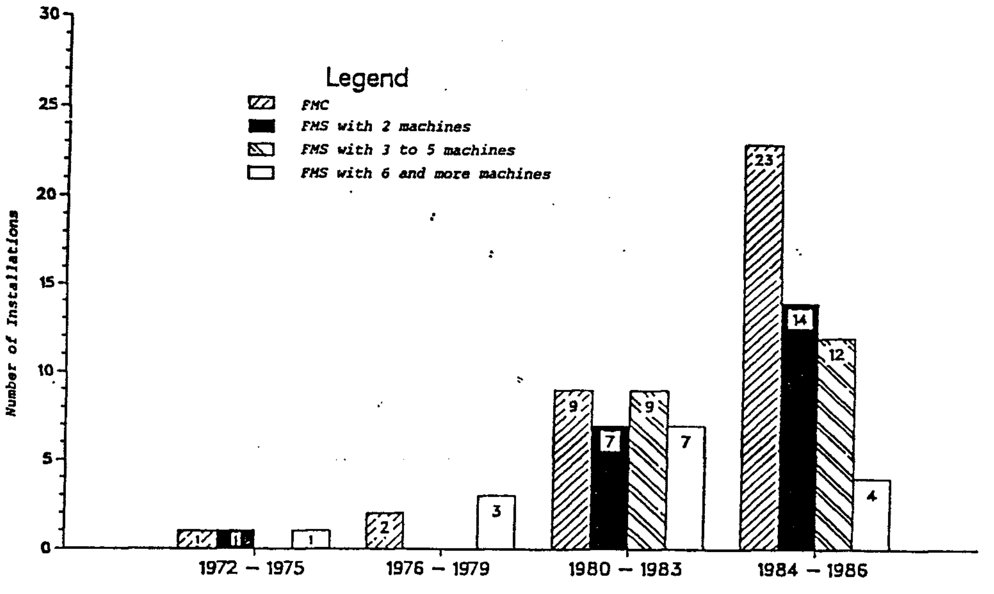
Figure 5: Trend in the Numbers of Installations of the Systems Recorded in Detail



If we now make a differentiated analysis of the number of installations on the basis of system size categories and periods of installation, we obtain the following figure (see figure 6): The initial stages of the development are marked by the use of flexible manufacturing cells and large-scale FMS (more than five machines). Smaller FMS (between two and five machines) were first installed in appreciable numbers between 1980 and 1983. In this period, the installation figures in the four size categories was still roughly in step. In the last two years, however, the trend has changed markedly. Flexible cells have increased abruptly, small FMS (two to five machines) are also on the increase (but less markedly so than the cells), while the increase of installations of large-scale FMS (more than five machines) is stagnating. It would therefore appear that in the future flexible cells and small-scale FMS will grow in importance.

It can even be said that it is the installation of smaller, less complex systems and cells - which also involve less risk - which has brough about the major increase in FMS/FMC in the last two years. The initial philosophy of the large-scale systems could therefore not justify itself for general use.

Figure 6: Trend in the Numbers of Systems in Use in Relation to System Size



1.3 Areas of Utilization

In specialized literature, the discussion on the introduction of flexible systems/cells frequently goes under the heading of 'flexibilization'.

FMS are intended to provide an economic means of producing the shortened production series which result from shorter product cycles, increased number of variant, smaller series, etc. Thus, for instance, Schulz (1983) argues: 'Present-day manufacturing technology is increasingly subjected to rapidly changing market requirements: increasing number of variants, shorter duration of product life, decreasing size of batches or more frequent changes of product. The answer to this is flexible manufacture: 'insular' manufacturing units, manufacturing cells, flexible manufacturing systems are all keywords which cover the whole range of manufacturing technologies'. Warnecke (1985) shares this opinion: 'The market for many industrial goods has changed to a buyer's market. The profitability of a given company is no longer governed solely by quantity production and sales, but the survival of many firms is dependent on acting more flexible on the market. For the company this means having to cope with an increase in the range of products and component parts, meet higher quality requirements and achieve shorter product-development and delivery times. And this also means that the efforts to achieve higher productivity which still exist today must be supplemented by the efforts to achieve higher flexibility. One means of achieving this is the introduction of highly automated flexible manufacturing systems for parts production'.

This argument is based on the assumption that the users of flexible manufacturing systems and cells have hitherto been highly productive in manufacturing large series on transfer lines, but that they have manufactured less flexibly.

The typical field of application of FMS/FMC lies between the two extremes of highly-productive but inflexible manufacturing of large series of the same parts on transfer lines and the highly flexible but less productive manufacture of many different parts in small and medium-sized batches, using universal machines (see figure 7).

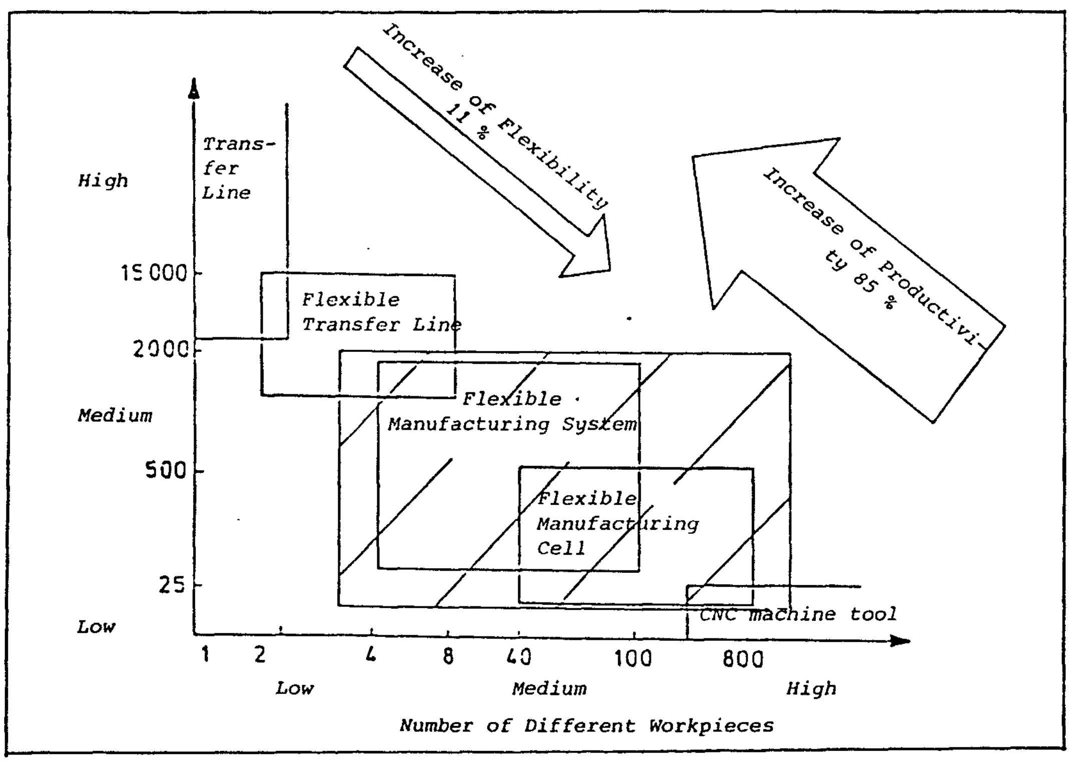
There can thus exist two completely different basic situations in the use of FMS. If we analyse the type of manufacturing process replaced by FMS/FMC it is clear that FMS/FMC systems are used in only 11 % of all cases due to decreasing batch size and increasing number of variants to replace transfer-line manufacturing, i.e. to increase flexibility.

In most cases of FMS utilization non-linked conventional or NC/CNC machines are being replaced, these machines having previously been used exceedingly flexible but with reduced productivity on small or medium-sized batches. This type of FMS/FMC utilization serves to increase productivity by raising the degree of automation of the manufacturing of small and medium-size batches, for which the rigid automation of the previous systems was not suitable.

This relationship is, however, dependent on the size of the systems installed. Whereas about one-third of the large-scale FMS (more than five machines) are still being used to replace transfer-lines, this proportion is falling off continuously with decreasing system size.

In FMS with between three and five machines the proportion is still just 20 %, with two-machine systems some 5 %, while flexible manufacturing cells in no case replace transfer lines. However, since the growth area is precisely with cells and small-scale FMS, in the future the aspect of productivity increase will grow in importance as against the flexibilization aspect.

Figure 7: Type of Manufacturing Replaced by the Introduction of FMS/FMC



2. Technical Features of the Flexible Manufacturing Systems and Cells Installed

As was stated in defining the flexible manufacturing system at the beginning of this report, an FMS consists of three sub-systems:

a) the machining system;

b) the material flow system;

c) the information system.

These can vary in terms of complexity and automation.

2.1 Machining System

The machining system is basically characterized by the types of machine tool used. For the 93 FMS/FMC on which information was obtained from the written questionnaire, the distribution of the types of machine indicated in the systems is as follows: there was a clear predominance of machining centres, with a figure of 56 %. Under the reply heading "sundry" covering special machines and formings, each of these categories had a share of some 16 % in the systems or cells.

As table 1 shows, the proportion of machining centres decreases with increasing system size and the other types of machine grow in importance. It is above all the special machines which are to a greater extent represented in the systems. Fairly large-scale systems thus frequently constitute a complement to the manufacturing process, whereas the smaller systems (above all the two-machine systems) replace earlier types of manufacture. The flexible manufacturing cells installed nowadays are 70 % based on the use of machining centres. Lathe cells represent only 23 %. The types of flexible lathe cells on show at EMO 1985 in Hannover, with newly developed automatic grip-jaw-changing devices, lead one to expect that flexible lathe cells will be used on a greater scale in the future.

An analysis of the machine-tool manufacturers shows that there is a broad range of firms offering FMS/FMC and there is no very clear instance of a dominant manufacturer. Matters are different in the numerical-control sector, where there is a very clear predominance of two manufacturers, namely Siemens and Bosch.

Table 1: Types of Machine Installed
(in percentage of the machines installed in each of the specified groups)

System size / Machine type	Cells	2-machine systems	3-5 machine systems	Systems with more than 5 m.	Total
Machining centres	71,4	77,3	67,1	40,5	56,6
Lathes	22,9	2,3	19,7	15,2	15,6
Milling machines	-	2,3	1,3	11,4	6,5
Drilling machines	-	-	1,3	3,8	2,3
Grinding machines	5,7	-	6,6	3,2	2,9
Sundry	-	18,1	3,9	25,9	16,2

2.2 Material Flow System

The types of linking equipment used to automate the material flow differ widely as a function of the system size (see table 2).

Flexible manufacturing cells based on a machining centre are predominantly (64 %) linked via a pallet changing device to a pallet pool generally comprising six, eight or twelve pallet points. On a lesser scale (20 %), rail-guided vehicles are used for transport. This makes it easy to extend the cell to a two-machine or multi-machine system.

With flexible lathe cells the workpiece transport is largely (40 %) carried out by a belt conveyor. Other possible technical solutions are roller conveyors or gantry loaders (20 % each). As the ranges on offer at the relevant trade fairs show, one can expect in the future that there will be a trend to gantry loaders as means of linking for flexible lathe cells.

The most frequently used linking device with two-machine systems is the rail-guided vehicle (41 %). The proportion of automated guided, which means wire-guided, vehicles (AGV) is still relatively low (9 %) with two-machine systems. With three-to-five machine systems the rail-guided vehicle is also the most frequently used linking device (38 %). Here, however, the scale of use of AGV is increasing (14 %). The conveyor belt is also a suitable linking device (19 %).

With systems comprising more than five machines it is the AGV which are used most frequently as the linking system, and the scale of use of rail-guided vehicles falls off. Of almost equal importance with the AGV, however, are the roller conveyors and belt conveyors (20 % each).

We can sum up by saying that overhead trolleys and industrial robots are seldom used as a linking device for FMS/FMC. The use of AGV increases with increasing system size and is therefore not likely to spread further, since the main growth is in the category of cells and small-scale FMS.

Table 2: Type of Linking (multiple listing possible; in percentage of the column)

System size / Type of linking	Cells (machining centres) n = 25	Cells (lathes and sundry) n = 10	2-machine systems n = 22	3-5 machine systems n = 21	Systems with more than 5 machines n = 15
Roller conveyors	8,0	20,0	13,6	9,5	20,0
Overhead trolley	-	10,0	-	4,8	6,7
Conveyor belts	-	40,0	-	19,0	20,0
Gantry loaders	4,0	20,0	4,5	9,5	6,7
Pallet-changing device linked to pallet pool	64,0	-	18,1	-	-
Industrial Robots	-	10,0	-	4,8	6,7
Rail-guided vehicles	20,0	-	40,9	38,1	13,3
Automatic guided vehicle	4,0	-	9,1	14,3	26,7
Others	8,0	-	22,7	9,5	6,7
No details	-	-	4,5	9,5	-

2.3 Information System

An essential prerequisite for the degree of automation of the information system of FMS/FMC is the presence of a central system computer. Such a central computer is an integrated element in just under half (46 %) of all the systems we have recorded in detail.

A differentiated analysis of the FMS/FMC solutions applied shows that the existence of a central computer depends very much on the size of the system. Whereas flexible cells on the basis of machining centres have a central computer in only 32 % of all cases and flexible lathe cells in no case at all, 80 % of the systems with more than five machines are fitted out with a central computer.

Thus there is an increasing trend towards the use of central computers as system size increases. A deviation from this trend can, however, be noted in the case of two-machine systems. They more often had a central computer than the three-to-five machine systems. One explanation for this is that the two-machine systems are frequently provided as a 'ready-for-use' system including a central computer by the manufacturers, whereas relatively larger FMS integrate machines from several manufacturers, so that the control software must be developed specifically.

If we now consider the functions performed by the system computer (if present) (see table 3), it becomes clear that the operating sequencing is carried out by computer in only 46 % of all cases. Most frequently, the computer is used for DNC-operating (83 %) and transport control (74 %). However, here again there is a clear dependence on the system size. There is a clear rising trend in computer control with increasing system size in terms of data recording, transport control and operating sequencing. On the other hand, the frequency with which the administration of the tools is computer controlled is falling off with increasing system size.

Table 3: System-Computer-Controlled Functions in Flexible Manufacturing Systems
(in relation to system size; in percentage of denominations)

Function / System size	2-machine systems	3-5 machine systems	Systems with more than 5 m.	Total
Direct numerical control	85 %	80 %	83 %	83 %
Recording of operational data	54 %	60 %	75 %	63 %
Transport control	62 %	80 %	83 %	74 %
Operating sequencing	38 %	40 %	58 %	46 %
Administration of tools	85 %	60 %	33 %	60 %
n =	13	10	12	35

If we consider the development in time of the use of central computers, we are struck by the fact that the earliest systems/cells up to 1978 were not yet provided with a central computer - with the exception of a large-scale FMS in the year 1972. Computer utilization was strong from 1979 to 1981, died off between 1982 and 1984 and is now - in the most recent development - thriving again in 1985 and 1986 as far as present knowledge of plans goes. An analysis by system size and year of installation shows that this increase can be attributed to the more frequent utilization of a central computer even in cells and two-machine systems. Since these are the two groups which are growing most strongly, it can be expected that further increases in the use of central computers will occur in the future.

3. Work Organization in Flexible Manufacturing Systems and Cells

3.1 Number of Shifts and Number of Jobs

Flexible manufacturing systems and cells involve comparable high levels of investment for the firms. It is frequently considered that economic employment of these capital-intensive installations is possible only with multi-shift working. The questionnaire sent to the users of FMS/FMC lead to the following result: almost all systems, independently of size, are worked at least on a two-shift basis. The frequency of use in a third shift exhibits slight variations according to system size, but cells and two-machine systems are used even more frequently in the third shift than larger systems. On average more than one-half of all systems are worked on three shifts. Consequently, the trend towards smaller systems and cells in no way hinders the application of multi-shift working.

If we consider the number of staff employed per shift per machine (see table 4), we find that the staffing in the second shift is lower than in the first shift, and the manning is even lower in the third shift. In the third shift, cells and two-machine systems are manned to about one-third of the level in the first shift; in the case of three-to-five machine systems the figure is 45 % and with large-scale FMS it comes to 57 %. The three-to-five machine system group exhibits the lowest manning levels per machine in all three shifts, which leads us to conclude that this size of system makes it possible to achieve exceptionally effective utilization of the machine operating staff. In comparison, large-scale FMS are more strongly manned and in particular the manning level in the third shift does not fall by so much. This is probably attributable to the fact that, with these complex installations, the risk of machine outages and the associated costs are felt more strongly than the higher labour costs for the supervisory staff employed.

Table 4: Number of Men per Machine and Shift

System size / Shifts	Cells	2-machine systems	3-5 machine systems	Systems with more than 5 machines	Total
First shift	0,868	0,904	0,643	0,904	0,830
Second shift	0,793	0,695	0,572	0,594	0,664
Third shift	0,305	0,325	0,293	0,518	0,360

3.2 Job Profiles and Job Patterns

Analysis of the organization of work with FMS/FMC refers, among other things, to the question as to what kinds of different jobs are established, what tasks are performed in the individual jobs and what form the division of labour consequently assumes.

When FMS/FMC are used the following functions are those which are primarily performed by the operators:

a) programming;
b) testing and correcting programmes;
c) responsibility for trouble-free operation of the system;
d) tasks concerned with the control of the manufacturing process;
e) pre-setting of tools;
f) making tools available, charging magazines;
g) fixing/palletizing of workpieces;
h) setting/re-setting of fixtures;
i) monitoring the processing operation, removing cuttings, etc.;
j) maintenance tasks;
k) minor repairs;
l) major maintenance/repairs;
m) checking dimensions during the processing operation;
n) final inspection of components processed.

The degree of division of labour in FMS/FMC depends on which and how many of these functions are brought together in one or several workplaces. In order to be able to classify the systems and cells recorded in respect of the division of labour carried out in each of them, two basic types of work organization were selected from the many options available; the features of these two categories are as follows:

Basic Type I (low degree of division of labour)

a) The system operators are responsible for carrying out the following tasks in the system either on a permanent basis or in job rotation:
   - testing and correcting of programmes;
   - making tools available, charging magazines;
   - palletizing workpieces;
   - monitoring the processing operation;
   - changing the fixtures,

   unless these activities are automated or are not required.

b) The system operators are in addition responsible for two out of three of the following activities:
   - responsibility for trouble-free operation of the system;
   - elimination of minor faults;
   - monitoring function(s) (during manufacture and/or final checking).

c) In addition to this, it is characteristic of a low degree of division of labour that there are no other jobs directly in the system which have a restricted range of tasks (except in the case of job rotation).

Basic Type II (high degree of division of labour)

The system comprises several different jobs, characterized, for example, by setting-up, palletizing, fixture changing and so on.

A classification of the systems into these two basic categories of work distribution is shown in table 5. As can be seen, a good half of all systems, in fact 56 %, operate with a high degree of division of labour.

Variations from this average occur with cells and two-machine systems. Whereas cells lie slightly below the average in respect to division of labour (50 %), some 70 % of the two-machine systems operate with a high degree of division of labour. Since it is precisely these system size categories which are in full growth, it is important to examine the reasons for the specific choice of division of labour in further investigations.

In general, the virtual division of the systems recorded into two categories of equal size, i.e. with low and high degrees respectively of division of labour governing manpower utilization, it may be supposed that the type of work organization is determined less by technical constraints associated with the manufacturing technology than with the predominant forms of manpower utilization encountered in the different manufacturing sectors or works (cf. Lutz/Schultz-Wild, 1983).

Table 5: Degree of Division of Labour in Systems According to System Size

System size / Degree of division of labour	Cells		Systems with 2 machines		Systems with 3 to 5 machines		Systems with more than 5 machines		Total	
	abs.	%	abs.	%	abs.	%	abs.	%	abs.	%
High degree of division of labour	17	50	14	70	11	55	6	55	48	56
Low degree of division of labour	17	50	6	30	9	45	5	45	37	44

n = 85 Installations

On the basis of this classification of work organization in FMS/FMC we can now describe, as follows, the range of tasks performed by the operators in systems with a low degree of division of labour (Basic type I):

Almost always (in more than 80 % of all cases) the operator carries out the following tasks:

a) testing and correcting programmes;
b) responsibility for trouble-free operation of the system;
c) making tools available, charging magazines;

d) palletizing workpieces;
e) setting/re-setting of fixtures;
f) monitoring the processing operation, removing cuttings, etc.

Frequently (in more than 60 % of the cases) the following tasks are performed in addition:
a) eliminating minor faults;
b) checking dimensions during the processing operation

The activities:
a) programming;
b) manufacturing control tasks;
c) major maintenance/repairs
are on the other hand included in the system either in upstream or downstream areas. The system operator takes on these tasks, if at all, only as an extra helper to a specialist from a department outside the system proper. This form of work organization corresponds to a large extent with the organization of work, for example, in the FMS of the gear factory at Friedrichshafen, in the framework of a pilot project carried out with parallel studies of work and social science aspects as an alternative to the traditional division of labour (cf. Schultz-Wild et al, 1986).

The tasks of the operators in systems of a low degree of division of labour are assigned to several jobs in the systems with strong division of labour (basic type II), for example:
a) machine operators;
b) pre-setters
c) pallet operators;
d) foremen/shift leaders/control-station staff;
e) tool-setters;
f) fixture setters.

Two main groups of workplace combination can be distinguished in this area:

a) <u>Basic type IIa: machine setter</u>

In this case it is above all the following functions which are carried out by the pre-setter instead of the machine operator:
- testing and correcting programmes;

- responsibility for trouble-free operation of the system;
- making tools available, charging magazines; and
- minor repairs.

The machine operator is thus trusted with a restricted range of tasks rather like that of a palletizer.

b) Basic type IIb: machine operator and palletizer

In this case the machine operator is responsible for tasks rather like those of a pre-setter, whereas the following tasks are principally removed from his responsibility and transferred to the palletizer:
- fixing/palletizing workpieces;
- monitoring the processing operation.

In some instances there is even an extremely marked degree of division of labour: pre-setter, machine operator and palletizer.

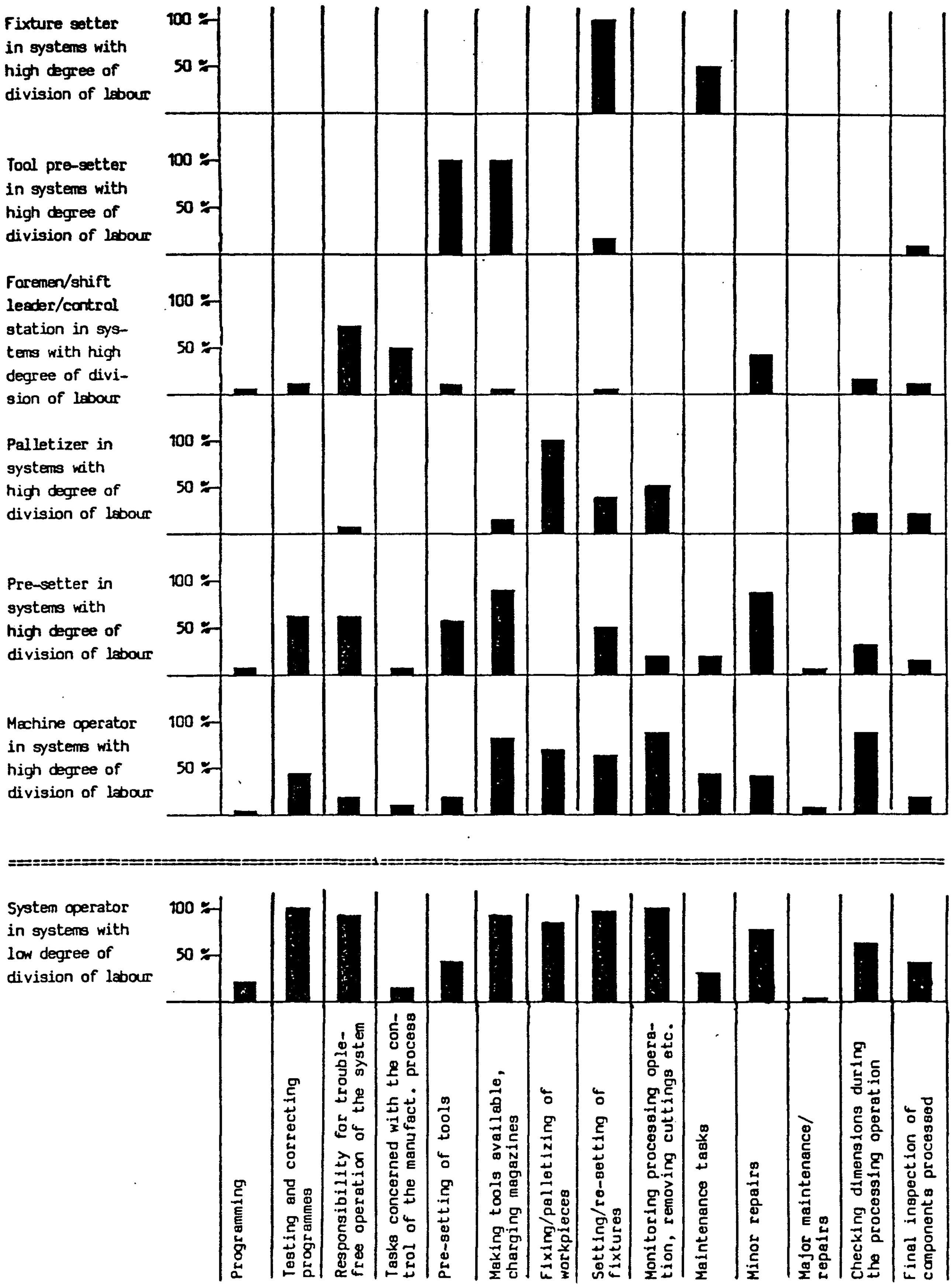
A precise comparison of the patterns of jobs arising with high and low degrees of division of labour is given in figure 8. As can be seen, the machine operator in systems with a high degree of division of labour does, on average, cover the total range of activities, but the frequence with which individual functions are assumed are strictly limited, for the reasons given above. In particular the functions:
a) testing and correcting programmes;
b) responsibility for trouble-free operation of the system;
c) pre-setting of tools;
d) setting/re-setting of fixtures; constitute the main items of activity of the pre-setter and the functions
e) palletizing of workpieces and
f) monitoring the processing operation;

are the main items of activity of the palletizer.

If the system includes a shift leader/control station, then it is here that the following functions are transferred:
a) responsibility for trouble-free operation of the system;
b) manufacturing control tasks; and
c) minor repairs.

Particularly highly specialized job designs include tool pre-setters and fixture setters. Where there is a tool pre-setter the range of activities is limited to the pre-adjustment and making available of tools, whereas where there is a fixture setter the task is restricted to the adjusting of the fixtures. In one case maintenance tasks were also carried out.

Figure 8: Job Profiles Covering Different Groups of Functions in Flexible Manufacturing Systems



4. Skill Requirements and Training

4.1 Work Organization and Amount of Further Training

All in all the survey's findings demonstrate clearly that the installment of flexible manufacturing systems and manufacturing cells creates in most firms a certain demand for additional skills. The personnel operating the system and to a certain extent other persons involved with the newly installed system, such as programmers and maintenance personnel will, in almost all cases, be confronted with initial on-the-job training periods of varying duration. This on-the-job training period usually coincides with the running-in phase of the new system, during which full manufacturing output often cannot be expected for technical reasons; the duration of this period is usually proportinate to the size and complexity of the new systems installed, while the training effects are naturally by no means uniform.

Moreover, explicit training programs are carried out (often in connection with the actual on-the-job training) in the form of off-the-job training courses offered by the manufacturers of machines, controlling equipment and software, or also by the training department of the user companies themselves. The nature and scope of these training programs and their participants are determined by a number of factors, such as basic skill level of employees, degree of innovation of the manufacturing technology installed, the type of work organization and its similarity or dissimilarity to the accustomed form of manpower utilization in the particular company. On the basis of the survey's findings certain statements can be made.

Table 6 shows a summary of the training courses conducted and their participants. In 78 of the 82 recorded cases (95 %) at least one functional group within a given company received special training in the operation of the new system. With the system using a low degree of division of labour there was only one case in which no further training was given; with the system having a higher degree of division of labour this was true in three cases.

Corresponding with the different job structures, the groups of people involved in the training courses differ with the degree of division of labour involved in the application of the system. Where there is a low degree of division of labour, the system operators - who clearly have a multiplicity of different functions to carry out - are almost always (in 95 % of all cases) given further training. Where the degree of division of labour is high, training for machine operators was given in only 75 % of cases; on the other hand, in these instances machine pre-setters are trained nearly as frequently for the new tasks. It is far more frequent to find the foremen, shift-leaders or control-station personnel included in the training when division of labour is high than when it was low (42 % resp. 11 % of all cases).

Whether the programmers and maintenance personnel receive training obviously depends less on the degree of division of labour with the system: in about 50 % of all cases programmers were trained, and about 20 % of the maintenance specialists. Only rarely (in 10 % of the cases) are pallet operators and tool pre-setters given special training in systems with a high degree of division of labour.

Table 6: Frequency of Training Program Participation of Various Functional Groups According to Division of Labour in the Systems (in % of the line; multiple listing possible)

Functional groups / Division of labour in systems	No training (% of systems)	Machine operators/ system operat.	Pre-Setters	Programmers	Foremen/ control station personnel	Maintenance personnel	Palletizers	Tool-setters
Low degree of division of labour n = 36	2,8	94,4		52,8	11,1	19,4		
High degree of division of labour n = 46	6,5	75,7	72,0	41,3	42,3	21,7	9,5	10,0
Total of systems n = 82	4,9	84,9	72,0	46,3	24,2	20,7	9,5	10,0

If a company provides training for a particular functional group, this does not necessarily mean that all the workers in this group actually receive training. Very different procedures are possible in this connection: they run from the one extreme, in which only a few individual workers are instructed during the initial phase of the system utilization and then pass on their knowledge to other colleagues (e.g. when shiftwork is extended), while the other extreme is to train the entire workforce for the system, even possibly including certain workers who are not currently, but may later be, involved in system operations.

An important indicator of the outlay necessary to provide the skills is the number of man-days devoted to training courses. This figure is naturally governed by the size of the systems and by the varying requirements and conditions of the application. To allow comparisons, table 7 shows the average number of training days in relation to the number of machine tools integrated into the systems.

Taking the average over all systems and all groups of workers we get a figure of 15,7 training days per machine tool integrated into the systems. This average outlay on training is only slightly lower in the systems with a high degree of division of labour than it is with those with a low degree of division of labour (15,6 and 15,8 training days respectively). However, the time devoted to training in individual cases varies very widely with the system size and also with the type of manufacturing process replaced by the flexible production installations:

- With those few systems which have replaced transfer-lines, the duration of training per machine tool is more than twice the overall average: with system with a high degree of division of labour 38 days of training were provided; with systems with a low degree of division of labour 27 days per machine tool.

- The average time devoted to training was correspondingly lower in the much larger number of flexible manufacturing cells or systems which had replaced stand-alone conventional or NC/CNC machines: where the degree of division of labour was high there were 12 days of training, where there was a low degree of division of labour 14 days of training per machine tool.

Table 7: Amount of Further Training courses in Relation to Type of Production System Replaced, the System Size and the Degree of Division of Labour in the Application of the Flexible System
(average values for all flexible manufacturing cells or systems recorded)

Type of production replaced	Stand-alone conventional or NC/CNC machine tools										Transfer line		Total		
System size	cells		2 machine systems		3-5 machine systems		more than 5 machine systems		together		2 and more machine systems		all FMS/FMC		
Degree of division of labour	high	low	high	low	high	low	high	low	high	low	high	low	high	low	total
Number of systems	17	17	13	6	7	6	5	4	42	33	4	3	46	36	82
Total number of machine tools	17	17	26	12	26	24	82	33	151	86	24	14	175	100	275
Number of training days per machine tool	16,7	14,1	8,2	10,8	13,1	14,8	12,1	14,5	12,1	14,0	37,8	26,9	15,6	15,8	15,7
Number of training days per FMS/FMC	16,7	14,1	16,4	21,7	48,6	59,0	198,6	120,0	43,6	36,5	227,0	125,3	59,5	43,9	52,7
Number of trained workers per machine tool	2,3	2,5	0,7	1,0	1,2	1,4	1,2	1,6	1,2	1,6	1,3	1,2	1,2	1,6	1,4
Number of training days per trained worker	7,3	5,6	11,2	10,8	11,0	10,7	10,2	9,1	9,8	8,5	30,3	22,1	12,7	10,0	11,5

- The lowest amount of further training in the systems which were introduced to replace individual machines is found for the two-machine system (average of nine training days), while the highest figure was found with the flexible manufacturing cells (average of 15 training days).

- Apart from the flexible manufacturing cells, the amount of training per machine tool is a little higher with systems with a low degree of division of labour than with a high degree. The differences are, however, only of the order of 1 to 2 days, i.e. some 10 %.

The total amount of further training in man-days is the product of the number of workers given training and the duration of training for each worker. The overall average shows that about 1.5 workers were trained in 11.5 days per machine tool. It is almost the general rule that with all system sizes, where the utilization involved a digh degree of division of labour fewer workers were given training than where the degree of division of labour was low, but that the duration of training per worker was higher with a high degree of division of labour than with a low degree. On an overall average, with a low division of labour 1.6 workers were trained for ten days, and with a high degree of division of labour 1.2 workers for just under 13 days of training. With more than 2 specially trained workers per machine tool, the number of workers involved was particularly large in the case of flexible manufacturing cells, but the duration of training per man was particularly low in these instances. There is an especially long period of training per worker (30 days with low division of labour, 33 days with high division of labour) for those systems which were introduced to replace transfer-lines.

There are naturally considerable differences in the training outlay even between the different groups of workers or functions, which are affected by system utilization to different extents. Such differences in the scope of the training process and the persons involved therein reflect the structure of manpower utilization, which varies very widely with system size and work organization (cf. section 3.2).

Table 8: *Amount of Further Training Courses for Various Functional Groups in the Works*
(Average values for all flexible manufacturing systems or cells recorded)

	Degree of division of labour	Machine/ system operator	Pre-setter/ other shop floor staff	Programmer	Foremen/ shift leaders/ control-station staff	Maintenance	Total
Man-days of training per machine tool	High	5,1	3,3	1,6	4.0	1,4	15,6
	Low	13,7	-	0,7	0,8	0,5	15,8
Man-days of training per FMS or FMC	High	19,2	12,7	6,2	15,1	5,5	59,5
	Low	38,2	-	2,1	2,3	1,4	43,9
Number of trained workers per FMS or FMC	High	2,2	1,0	0,5	0,5	0,5	4,7
	Low	3,6	-	0,3	0,2	0,3	4,3
Man-days of training per worker	High	8,6	12,9	13,6	31,5	11,0	12,7
	Low	10,7	-	7,4	13,7	4,5	10,0

With systems having a low degree of division of labour the training is above all directed at the system operators. On average, more than 3 workers were trained per system each for just under 11 days. Even when the degree of division of labour is high, the operating staff in the strict sense (i.e. machine operators, machine pre-setters and, in rare cases also, palletizer and tool pre-setters) as a whole constitute the largest group given training; the number of workers trained on average per system is, however, lower with a high degree of division of labour. Complementary, where the division of labour is high more workers of the other functional groups (such as foremen, shift-leaders, control-station and maintenance personnel) are included in the training.

Where the degree of division of labour is low the duration of training per worker is higher for the operating personnel than where the degree of division of labour is high, while the relationship is generally the converse for most of the other groups of workers. The highest amount of training - more than 50 days of training per man - was given to the control-station personnel in systems with a high degree of division of labour; however, this occured in comparatively few cases.

The average values referred to for all the cases examined necessarily hide some part of the variations in the training policy procedure of the user companies when they introduce flexible manufacturing technology. Nevertheless, the close relationship between the choice of certain work organization options and the scope of the training programmes can be clearly seen.

4.2 Skill Requirements and Vocational Training Policy

From the point of view of vocational training and labour policy it is of particular interest that the request made in recent discussions about the future of the factory, namely that the work structures on the shop floor should realize a lower degree of division of labour (cf. e.g. Brödner, 1985), clearly does not have to be acquired at the price of generally increased training expenditures in the user companies. The number of man-days devoted to training per newly-installed flexible system is actually markedly higher with applications involving a high degree of division of labour than with a low degree (60 days to 44 days of training). If consideration is given to the number of machine tools employed, then - as already stated - the duration of training is only a little higher with a low degree of division of labour than with a high degree thereof. Among other things, such differences can naturally be connected with the varying initial qualifications of the personnel available and also whether the introduction of flexible manufacturing technology is at the same time associated with a change in the normal in-plant forms of manpower utilization or not.

It can be assumed - and was confirmed in the case studies - that in many cases the staff from the corresponding conventional or replaced manufacturing process is not simply taken over, but that a broader selection process in terms of creaming off took place. A policy of this kind is quite frequently practised specially at the time of the first introduction of new manufacturing technologies, since this reduces the training expenditures required in connection with the technological change; it can, however, soon come up against the problem of an inadequate supply of workers able and willing to become involved in new jobs and training, where there is a large-scale introduction of new manufacturing technologies. Consequently, the question of the availability of relevant skills and qualifications is of considerable importance in connection with the further dissemination of computer-aided flexible manufacturing technologies.

The information summarized in the job profiles and relating to the task or function areas covered by various groups of workers (see section 3.2) seems broadly compatible with the content of the vocational training approved in the Federal Republic of Germany at the end of 1984 within the framework of the new regulations for the trades in the metal industry. The vocational training of both the industrial mechanic (production technology branch) and that of the machine operator for lathes, milling machines and grinding machines seems likely to meet the modified qualification requirements in connection with the application of flexible manufacturing installations (cf. Buschhaus et al, 1984; Preiss, 1985).

Since the administrative implementation of the new trades which have been approved is not yet terminated and consequently the vocational training of the first annual groups of young people to the new training arrangements requires a period of 3.5 years, the firms will actually receive young skilled workers qualified to this extent only at the end of the 1980s/early 1990s.

However, it can be expected that even now there will be to a certain extent an adaptation of the training of young people to the recognizable new requirements on the basis of the increased utilization of computer-aided manufacturing technologies. This is also possible, up to a certain extent, in the framework of the traditional vocational training schemes and has been achieved in the past by individual firms and training centres on a more or less broad basis. It may be asked to what extent such anticipatory action in respect of the future training schemes will be incorporated in the on-going vocational training of young people in connection with the introduction of new types of manufacturing equipment.

For many reasons - not least the rapid development of technology - everything seems to show that increased importance will attach to further training of adults as a result of technical innovation. This is by no means only a matter of dealing with the bottlenecks which will occur until qualified skilled workers are available from the updated apprenticeship programs. It is much more the case that re-training of adults can also - and precisely here - provide a major contribution towards avoiding cutting the link between the existing operational workforces and the new technical developments; otherwise they would be exposed to the risk that in the short or long run they would be pushed out of their jobs, so that there would be a greatly increased risk of employment and labour-market problems for them.

From the point of view of vocational training policy it is of considerable importance to determine the content, the form and the objectives of such procedures for enabling adults to obtain higher qualifications. In general this area is in Germany, compared with the apprenticeship training within the so called 'dual system', much less subject to legal regulation or standardized in a way that guarantees the transferability from one company to another of the qualifications acquired. In principle there always exists the risk of too narrow an approach to qualification - e.g. towards the specific requirements of the respective technical equipment in a plant - which raises problems in respect of the longer-term potential of the acquired skills both for the worker and for the firm.

It is in this context of particular interest to see what role is played in these cases by the training measures run by the suppliers of modern computer-aided manufacturing equipment. It is precisely in connection with the introduction of technical innovations that so-called customer training courses run by the manufacturers have become of great importance in recent years.

More-or-less systematic instruction and training of customers' staff has for a long time been usual in connection with fairly complex machines and installations. However, in the meantime, for example, certain machine tool producers offer not only the product itself but also the so-called 'teachware', i.e. a systematic training of the customers' staff, frequently as a separate paid arrangement.

In connection with the export of the machines and FMS, such training packages are offered not only on the national market. Particularly from an international point of view it would be interesting to find out how far such forms of adult training have begun to be accepted, so to speak, beyond the relevant national vocational training systems, in the context of the introduction of new technologies, accompanied perhaps by a certain international standardization in this field of skills and qualifications.

5. SUMMARY

To sum up, the principal results obtained from the survey by a written questionnaire sent to companies using flexible manufacturing systems and cells can be listed as follows:

a) FMS/FMC are utilized mainly in the machine building industries in larger firms (more than 500 employees).

b) Utilization has risen steeply in recent years: between 1983 and 1985/86 the total number of installations has doubled.

c) Flexible manufacturing cells and small-scale FMS (maximum five machines) exhibit the greatest rate of increase; large-scale FMS are stagnating or even falling off.

d) FMS/FMC are principally (85 %) installed to raise productivity by increasing the degree of automation; only 11 % of the installations were mainly intended to increase the flexibility of the manufacturing process.

e) Machining centres - 56 % of all integrated machine tools - represent the most important type of machine; in fairly large systems the importance of lathes and special machines is increasing.

f) The choice of the automatic transport and linking equipment used in FMS/FMC depends greatly on the size of the system and on the types of machine tool integrated; it is not possible to indicate average trends.

g) Just over 50 % of the systems installed operate without a central computer. In the future, however, increased use of central computers is to be expected.

h) Almost all FMS/FMC are operated on at least two shifts; approximately 50 % of all the installations are even run on three shifts.

i) The degree of automation of FMS/FMC allows to use considerable less personnel in the second and third shifts compared to the day-shift.

j) The choice of the type of work organization, and in particular the degree of division of labour in the system, is governed less by the constraints of the manufacturing technology than by the traditional structures in the firm; this is shown by the fact that the ratio between systems with low division of labour and systems with high division of labour is about 50:50.

k) The choice of work organization also affects the duration of the training given upon introduction of the system and the group(s) of workers involved therein. The type of work organization does not, however, seem to have any significant influence on the overall duration of the training measures.

II. DESCRIPTION AND ANALYSIS OF SELECTED EXAMPLES OF THE UTILIZATION OF FLEXIBLE MANUFACTURING SYSTEMS

1. Introduction to the Selection and Presentation of the Case Studies

Naturally the use of a questionaire reveals only the more general characteristics of the utilization of flexible manufacturing systems. The exact technical-organizational design involved and the framework conditions prevailing within the individual company are, as our investigations have shown, extraordinarily differentiated. Therefore other methods of investigation must be additionally employed particularly when essential factors on which decisions were based are to be analysed, as well as the design of introductory processes, the experience gained and the consequences derived therefrom.

Thus five case studies were carried out on the basis of the material obtained by questionaire, making use of extensive interviews with experts following set guidelines and including on the site inspection of those flexible manufacturing systems to be described within the companies. In the selection of the case studies particular attention was given towards including the entire range of work organizational concepts. It was also intended to examine different technical solutions, particularly with reference to the information systems and linking facilities. In order to examined cases to be comparable amongst each other, but also with the aim of covering the entire scope of technical-organizational solutions, all five cases examined are manufacturing systems consisting of several machines.

The case studies and similarly the survey results are presented according to a uniform pattern which is oriented to the central questions formulated by the investigation. First of all an exact description of the systems' technical layout and their operative sphere is given while the respective planning and introductory processes are also described in detail, whereby the grounds and reasons on which the decision in favor of an FMS were based are elucidated, as well as the experience then gained and the consequences drawn, particularly with regards to further system planning.

The description of the chosen form of work organization, that is staffing, the division of labour within the systems, the distribution of tasks between the teams assigned to the flexible manufacturing systems and the preceding and following areas, as well as the utilization of the facilities in terms of time (shift system) constitute the second point of emphasis.

Finally the company personnel selection strategies and the measures taken towards qualifying this personnel for work on the flexible manufacturing system are described.

Within the individual case studies the intention was also to reflect the individual framework conditions relevant within the respective companies. Lastly the attempt is made to summarize the findings of part II of the study and to elucidate tendencies of company strategies in the use of flexible manufacturing systems.

2. Presentation of Five Case Studies

2.1 Case A

a) System Configuration and Company Framework Conditions

Case A deals with a flexible manufacturing system for prismatic casing parts which is in use in series production of a large-scale enterprise in the field of driving and transmission technology, farm machinery and the construction of industrial facilities. The company employs approximately 20.000 persons, 13.000 of which work in the main plant where the flexible manufacturing system is installed.

The flexible manufacturing system consists of three machining centres which are linked by means of a rail-guided vehicle. The FMS is equipped with a system computer which deals with the functional areas of DNC operation, transport control, order scheduling, tool management and the recording of operational data. The FMS supplements a transfer line.

Introductory Process

Two factors were influential for the decision to introduce a FMS. On the one hand there was an immediate need to increase the production capacity of a certain motor casing type being manufactured on a transfer line. The installation of a second identical transfer line was out of the question due to the fact that the increased requirements was only temporary and not expected to be constant. An alteration in order to expand the existing transfer line would have caused too great a disturbance of the ongoing production process which, particularly during a period of maximum demand, would have been highly undesirable. A FMS, however, offered the possibility of manufacturing other workpieces with minimal conversion expenditures after the present maximum demand. In return it was accepted that a larger number of units would be produced by the FMS than on the transfer line.

The second reason for introducing an FMS was the possibility the project granted for acquiring know-how in the field of this new form of technology. This 'pilot character' of the project had particular influence on several aspects of technical design (for example the degree of centralization of the information system) which otherwise would probably have been solved somewhat differently from the standpoint of 'hard' economics.

The reduction of personnel costs had no influence at all in favoring FMS, on the contrary, the FMS actually requires more personnel than the transfer line does. The aspects of humanization of work also played a subordinate part.

The initiative to install a FMS came from the production engineering department and had to hold its own against objections voiced from the standpoint of business economics. A team was formed for the planning of the project, consisting of the head of the production engineering department (project director), representatives of the work planning department, the manufacturing control and manufacturing department as well as representatives of the companies supplying machinery and control equipment. Also the present system leader (shop engineer) participated from a very early stage on.

An 'interdisciplinary' project team, including representatives of business economics and members of employee representation for example, was not attempted. The works council was informed at the beginning of the planning in accordance with the Work Constitution Act. The employees affected were informed after the decision in favor of the FMS had been made and the system manufacturer had been selected. At this point training measures were also begun with, which will be dealt with in detail later on.

On the one hand the project team was concerned with technical questions such as

- development of control software for the information system,
- tool planning,
- location planning (here the main problem was the lack of ample space within the given manufacturing halls),
- planning of the cooling system and the
- planning of the computer location.

On the other hand the profitability of the FMS had to be established before the decision for the former could be made.

Due to the fact that the comparison of costs per piece between the FMS and the alternative of transfer-line manufacturing would have favored the former, this form of calculation was not used. Instead, manufacturing of the workpieces on conventional tool machines was compared and the gain in productivity attained in switching over to CNC-technology was ascribed to the FMS. Furthermore, the comparative calculation was based on 3-shift operating, which was not achieved in actual system running practice, however, due to frequent system failures. The alternative of employing unlinked CNC-machines was not considered, due to the pilot character of the project with the aim of gathering experience in linking systems and automation of system control. Being well aware of the 'shortcomings' of this kind of justification and also due to the fact that a form of investment calculation doing full justice to the complexity of such systems not being available as yet, the calculation of profitability therefore was not an essential part of the basis on which the decision was made.

In comparison, the planning of the system's technical design (choice of machines and linking) presented virtually no problems whatsoever. The planning of the information system necessitated considerable expenditures, particularly the development of control software. This point subsequently posed the main problem of the planning process.

Experience with the FMS and Further Planning

Although the system operators were generally content with the FMS, particularly considering its pilot character and the aspect of acquiring know-how, a number of problems arose nevertheless.

The availability achieved did not quite reach the initial expectations of 80 %. This was mainly due to control software. The strategy of giving priority to prefabricated parts in transport proved a disadvantage because the washing machines unexpectedly formed an impasse. Software alterations, however, always require the support of the manufacturer and often cause unexpected effects in other areas.

A further problem arose concerning the refrigeration cycle, which was interrupted by machine standstill whereby excessive pressure heated the refrigerant so strongly that an additional cooling aggregate had to be installed which in turn caused spacial problems. Due to these difficulties among others, the planning and introduction phase of six to nine months lasted two years instead.

The developments concerning the product spectrum were positive. The handling of peak production requirements such as up to 600 gear casing units per year, for example, remained predominant but recently pre-production series and prototypes were handled more frequently, thus partially allowing the development phases for new products to be shortened considerably.

The company dealt with in this case study is planning two more FMS which are to integrate the experience gained by running the initial system. It is planned, for example, to dispense with a systems computer, thereby simplifying the information system to a certain extent. Tool supply is to become part of the system.

b) Work Organization and the FMS

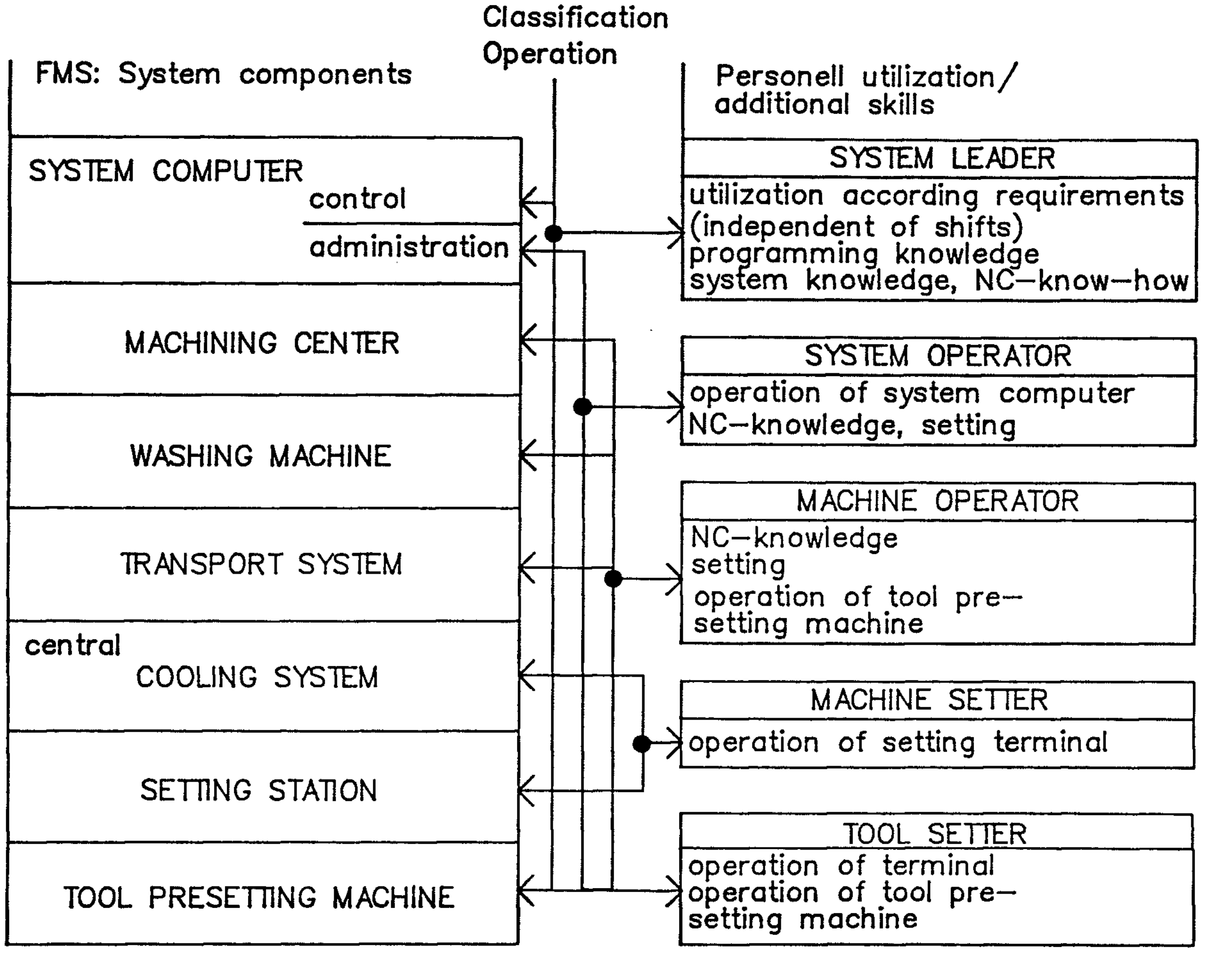
The choice of the type of work organization on the FMS took an interesting course in this company.

During the planning phase a structure based relatively strongly on division of labour was opted for on the grounds of talks with other companies using FMS/FMC and also in accordance with the kind of division of labour so far prevailing in the company. The jobs of a system leader, system operator, machine operator, setter and tool pre-setter were created and assigned specific tasks (compare figure 9).

During the introductory phase, however, a considerable susceptibility to failure and resulting lack of system availability became apparent, which has not yet been entirely corrected to date.

Thus a number of measures aimed at increasing system availability were carried out which included, among others, the introduction of a form of work organization based on less division of labour and making use of qualified employees with a better general understanding of the total system. Therefore the jobs and tasks of the system operator, machine operator and the setter were combined so that all operators were able to cope with all tasks directly pertaining to the system.

Figure 9: Planned Personnel Utilization in the FMS



There are mainly the functions of

- testing and correcting programmes,
- responsibility for trouble-free operation of the system together with the system leader,
- charging tool magazines,
- fixing/palletizing workpieces,
- setting/re-setting of fixtures,
- monitoring the processing operation,
- correcting minor disturbances as well as
- controlling workpieces during and after machining.

The jobs of the system leader and the tool pre-setter were retained.

This form of work organization has proven satisfactory to date. According to company opinion, work organization should not be rigid, but should be able to be re-adjusted again and again as necessary to do justice to current conditions and requirements.

The system is presently being run in 2 1/2 shifts, that is, the late shift begins two hours after the early shift ends. During these two hours and also for two hours after the late shift ends the system is run without personnel. The long term objective is to run the system in three shifts, which at present is not possible due to the system's considerable susceptibility to failure. In the case of three-shift running problems of personnel availability are likely to arise, particularly with regards to maintenance. A possible solution would be to utilize highly qualified employees during favourable working hours and to staff the system with lesser qualified personnel during the less attractive working hours, thereby also falling back on a stronger division of labour.

At present shift staffing is as follows:
The system leader works on the day-shift which means he is only available for a short period of time at the beginning of the late shift and can, however, be called upon in urgent cases. Two operators and one tool pre-setter, who not only works on the FMS but also on other CNC-machines in the hall, are employed per shift. Maintenance is also carried out in two shifts.

While the personnel employed on the FMS is presently being paid according to measured day work, this is not regarded as a satisfactory wage form for system related work and new wage forms are being sought, such as premium pay with a system utilization/units produced premium. These concepts will require some time still, due to the fact that alterations in the wage system are difficult to bring about (this being one of the works councils' main fields of co-determination and also due to the conversion of wage calculation etc.). The FMS-system leader is one wage group above the operators who are grouped about the same way as the operators at stand-alone tool machines are (wage group 7-8 of the North Rhine-Westphalian wage agreement). Within the wage groups there is further differentiation according to an internal work evaluation grading scheme. On the basis of this calculation the FMS-operators earn one work grade more because they carry more responsibility than the other machine operators.

c) Personnel Selection and Training

In the staffing of the FMS, preference was given to 'good' employees experienced in handling NC/CNC machines. The initiative was taken by the production manager or foreman who spoke to the individual employees. In terms of formal qualifications the operators are skilled workers and the system leader is a certified foreman (shop engineer).

As the system operators had worked in two shifts beforehand, their deployment to the FMS did not mean having to accept less favorable working hours. The payment of an additional work grade also formed an incentive. Prior to employment on the FMS special training measures were carried out: The system leader who was already a member of the project team, underwent approximately four months of training by the machine and control system manufacturers whereby this training focused on the use of the central computer and the program for order and operation sequencing. The operators were also trained by the machine and control system manufacturers and were mainly instructed in specific machine and control system know-how, whereby their training lasted only approximately two weeks. Maintenance personnel also received training by the machine manufacturer, although there is no personnel specifically responsible for FMS maintenance.

Approximately 60 % of the external training was carried out during working hours and about 40 % outside of working hours (evening courses). At present there is only one system leader for the FMS which makes this position an impasse of sorts. The future system leader(s) is (are) to be recruited from the current operators, promising candidates being scarce, however. Presumably the 40 % training outside of working hours also has a somewhat deterring effect.

Apart from the external training courses 'learning by doing' was of great significance. The running-in phase lasted approximately three to six months. All in all there were no major qualification gaps to be bridged, as a policy of creaming off had already been pursued in the pre-selection of the system operators. This policy has not met with any limitations to date due to the fact that the number of persons required for the FMS is relatively small compared to the total number of company employees. The FMS being an expansion investment there have also been no problems with employee transfers or redundancies.

2.2 Case B

a) System Configuration and Company Framework Conditions

The FMS described in case B is installed in a branch plant of an enterprise in ancillary industry with 20.000 employees, manufacturing axles, driving and transmission systems and gears. The branch factory dealt with here employs approximately 4.500 persons.

The FMS installed in 1985 consists of eight machining centres, arranged in groups of twos and threes and linked by a conveyor and a pallet exchanger. A system computer is not employed, but a linkage to a CAPM-system should be possible in future allowing a planning of the A-parts (after ABC-analysis) while the manufacturing of the other parts pre-determined in weekly blocks, is controlled by a PC attached to the FMS.

Introductory Process

The FMS supplements a transfer-line for axle elements which is designed for a capacity of 60.000 units per year with batch sizes up to 300 pieces and which is more flexibly equipped than originally planned, having a computer guided overhead trolley and a machining centre. The FMS handles batch sizes between 1 to 50 units in approximately 40 variations with processing times of about 6 to 25 minutes. An output of approximately 30.000 axles per year is achieved, while investment expenditures have remained the same and resetting periods were greatly reduced.

Thus the FMS served the purpose of increasing capacity and attaining a considerably larger number of variations at the same time. Therefore unlinked machine centres were also considered as an alternative. A comparative economical calculation showed only minor rationalization advantages (unit costs) for the FMS, however other advantages were seen with regards to through-put times and reduction of personnel costs. Due to the wide machining scope a machining centre would not have been adequate, without automated transport idle periods and manufacturing control problems and lastly longer through-put times would have resulted.

Concrete system planning was carried out by an internal work group with five persons (among them the factory manager and the heads of the manufacturing and work planning departments) and lasted approximately six months. The introductory process required five to six months - all in all, full system functioning was achieved within a year, thus actually falling short of the expected planning and introductory period. The works council was roughly informed, but its actual participation was minimal as wage questions were given greatest priority by the former.

The choice of the machine manufacturer was the most important planning task due to the fact that the demanding machining tasks to be integrated by the FMS (minute tolerances, high cutting forces and small metal cutting volume) could not be handled by standard machines, but required specially designed machines instead. The system's technical layout was further determined by capacity requirements. With regards to the information system the philosophy was to favor a less complex design and to avoid a high degree of automation so as to keep the susceptibility to failure as low as possible. Furthermore the FMS's work organization which will subsequently be described was also determined during the planning phase.

FMS Experiences and Further Planning

Case B is that of a relatively 'young' FMS so that not much experience has been gathered to date and it is not possible to make any definite statements on problems posed by the system.

It is interesting, however, that no notable modifications were carried out when compared with the original planning. System availability of 90 % was aimed for. The only problem referred to, although not explicitly, was that the failure of a single machine results in the standstill of the entire group. While the groups of threes can replace each other, all parts must be handled by the group of two machines, which thereby form an impasse.

The company in case B could draw on experience gained in operating a larger FMS in their main plant, which was, however, in the case of FMS introduction described here, only relevant to a very limited extent. At present two further FMS with seven and four machines are being planned for plant II situated at the same location where the FMS described has been installed.

Within the larger plant I it is intended to expand an existing FMS consisting of seven machines so as to finally comprise approximately 50 machines, which again are to be arranged in groups. It is interesting to note that different 'system philosophies' are being pursued. While the aim in plant II is to create insular solutions which are relatively easy to survey (permitting complete processing and reducing through-put times to one day), whose degree of automation is not too high and which can be interlinked or attached to a PPS later on, plant I will be using a central computer for operating sequencing and employing a technician or engineer as qualified system leader.

b) FMS and Work Organization

The FMS, as well as the surrounding area of manufacturing operates in two shifts. The three persons employed per shift perform their work in turns (job rotation). Two of them feed the machines, that is they mount and unmount workpieces and remove or exchange fixtures if necessary which requires approximately 1 to 1 1/2 hours. Mounting and unmounting requires very little time. As there are only two intermediate storage places and the operation cycles are mostly very short, there is usually a time buffer of only 15 minutes.

The third employee supervises the manufacturing process and operates the machines. Due to their changing workplaces, the chosen form of work organization, which is also intended to reduce replacement problems, means a relatively low degree of division of labour for the employees.

In this case a very wide scope of tasks is performed outside of the FMS, including programming, tool pre-setting, service tasks, maintenance and repair as well as control of finished parts and also manufacturing control tasks. Furthermore, system external departments participate in testing and correcting programs, share responsibility for flawless system running and perform minor repairs.

The FMS employees are paid according to a piecework system, which is limited to 150 % within the company and also includes an allowance of 30 % for periods of time beyond employee influence. New wage forms have been considered ('utilization premium') although there is a great deal of reservation about this due to the fact that the works council regards this area as its most important field of activity. Within the FMS there is no formal wage differentiation, it depends on the individual employee whether he has reached the final wage group or not. In order to provide an incentive, the wage grading within the FMS is one grade above the rest of the manufacturing area.

c) Personnel Selection and Training

The future FMS employees were selected at the same time that the machines were ordered. They were all skilled workers who had previously worked with machining centres and/or special machines and who were familiar with NC-technology. Some of them were young skilled workers with experience of the control system used on the FMS, while others were good employees selected from the manufacturing area closer to the FMS.

Training was embarked upon immediately afterwards. Service personnel for mechanics and electronics received three days of instruction by the machine manufacturers. A part of the future machine operators took part in courses offered by the machine manufacturing companies and subsequently instructed other employees on the system for approximately two weeks. In this manner a larger group of qualified operators finally became available, the best of which were employed on the FMS, while the others continued to work at stand-alone machines and thus formed a personnel reserve.

Case B therefore also pursued a policy of creaming off. At the same time, however, the described strategy of personnel selection and utilization must also be seen within the context of the general policy of personnel development followed within this company. The previously mentioned principle of job rotation which also found expression in the form of personnel selection is intended to become more and more the philosophy also determining personnel utilization of employees at stand-alone machines, in order to promote the availability of a more flexible team in future. This also includes the increasing utilization of skilled workers (partially also of persons with less specific training backgrounds such as automobile mechanics), and a relatively strong engagement in training and instructing young recruitees, which does, however, remain oriented to company requirements. At present, two thirds of the employees are semi-skilled workers, whose further training - apart from the training for operating several machines practised in the manufacturing area (job rotation) - has not been regarded as very urgent so far.

2.3 Case C

a) System Configuration and Company Framework Conditions

The FMS in case study C consists of two twin cells (four machining centres) without central computer, which are linked by automated guided vehicles. It was installed in 1983 in a machine building company employing 2.000 persons all in all and manufacturing a wide range of tool machines up to FMS themselves.

The FMS is used in the manufacturing of large parts (work tables, stands, etc.) and replaces older, stand-alone NC-machining centres. Gradually further parts of conventional radial-drilling machines were shifted to the FMS so that presently 20 variations in batch sizes between 15 and 30 pieces with processing periods of 8 to 100 minutes belong to the part range of the FMS.

Introductory Process

The initiative towards installing a FMS came from the work planning department, and it required a year's time for the idea to be accepted. This phase was accompanied by discussions and controversy within the factory management and production management, while the works council as well as a member of the supervisory board favored the concept.

FMS introduction was not only based on the attempt to improve the company's manufacturing conditions but also motivated by the intention of opening a new market in developing flexible manufacturing systems. The following points are to be stressed from the standpoint of the system user:

- The aim was to construct the most adaptable manufacturing equipment possible, which would not only allow certain alterations during the introductory process but also permit changes in long term use in terms of conversion flexibility. A planning study had also shown that the expansion or replacement of the old manufacturing equipment by a transferline would have resulted in advantages in terms of productivity in the case of normal operating, but that these would have been nullified by problems and costs arising during the running-in period as well as by restrictions with regards to adaptability and modernization.

- Acceleration of through-put times in order to reduce the costs of material stocks was a further objective. Moreover, the shortening of planning scheduling increasingly demanded by the market was an important consideration. In this context the main pressure is exerted by the sales department, because the terms of delivery demanded by the market have dropped within several years from 18 to 22 months to about 12 months and partially even down to 6 months.

- Furthermore an increase in flexibility of capacities without personnel increase was anticipated, that is to say considerable rationalization effects. This was to be achieved by an acceleration of through-put times based on an improvement of manufacturing flow and a reduction of machining times (due to bilateral machining of workpieces and reduced fixture mounting times).

From the standpoint of the machine tool manufacturer the following are the main reasons for introducing the FMS:

- Anticipating that FMS would prove to be a development in the field of machine tools of general significance, the intention was to venture into this field with a company product which would round off the range of products offered by the company. On the one hand this meant finding market openings for a new product, but on the other hand defending the market shares of the products so far manufactured by integrating as many components from the company's own standard program into the FMS as possible.

- The installation of in-house reference equipment was regarded as lending additional weight to advertising and promotion.

- Moreover it was hoped that by running a FMS oneself experience and knowledge could be gathered which in future manufacturing could be utilized in terms of product improvements and gaining a lead over competitors with regards to experience. This particularly holds true for the relatively strong engagement in control technology and software development resulting after the use of software from other companies had caused great difficulties. Venturing into the development of user oriented software is also a future investment for a manufacturer of machine tools which could find most widespread use in all company products.

The works council's backing of the FMS also results from this manufacturer's perspective, viewing a potential expansion of sales in this case as a contribution towards securing employment. Moreover the alternative solution of a transfer line would have been less favorable in terms of the wages and working conditions to be expected. The FMS, however, is regarded by the works council as a possibility of up-grading the manufacturing workers' wage structure.

Considerations of profitability within the framework of planning came to the conclusion that the FMS would pay for itself within a span of 3 and 7 years depending on which manufacturing programs the calculations were based upon.

The works council not only participated in the decision making process but, unlike the future system leader, also was partially included in the actual planning process. It was only after the machines were installed that the system leader began to play an important role, selecting the team and watching over the initial manufacturing phase.

FMS construction and running-in required more time than originally planned. Concrete planning was started in 1981 and the system was installed towards the end of 1982. After one of the twin cells began running in July 1983, the system was run at full production capacity from November 1983 on. The delays compared to the planned schedule were mostly due to the fact that with the company's overall low staff level no special personnel had been assigned with the development of the company's own FMS and the manufacturing department had to produce the machines required for the in-house FMS while having to give priority to customer orders at the same time.

FMS Experience and Further Planning

The FMS' unexpectedly high productivity initially led to blockages in machining areas situated before and after the system when the latter was being run to full capacity. Thus the FMS was partially not fully utilized. It was only when all available capacities had to be utilized due to a risen overall demand and the total manufacturing planning was re-arranged that this problem was solved.

The problems with the FMS' technical arrangement mostly had to do with machine control and tool capacity and also with transport. Because the tool magazine of 40 tools per machine is fairly small, the feeding of the FMS with a larger part mix within a operating planning cycle is relatively limited. Three or four different workpieces within a machining program usually exhaust the tool capacity. An expansion of the tool magazines is prevented by the system's spacial design.

The initial problems coordinating the automated guided vehicles with the system sequence, which were partially caused by signal transference problems, have been solved in the meantime. Their relatively high susceptibility to failure and lack of speed in certain situations does remain a handicap.

Considering the stated availability of 85 % this FMS must, generally speaking, be regarded as a successfully operating system, even though this performance level was only reached after a number of partially demanding adaptation processes and modifications. This also somewhat detracts from the original intention of having a prototype which could be put to immediate use and act as a reference system.

Moreover, the intended capacity for expansion could not be attained due to lack of reserves in certain system components. The reason for this is not only to be found in the unavoidable mistakes arising in any pilot project, but in the state of technology of the time, which either did not offer certain possibilities or, if so, then their price/performance relationship did not permit their use.

Consequences should be and were drawn from the experience gained, particularly for FMS offers:

- Simplification of machine control,
- utilization of a central computer with separation of cell control from system control,
- as far as possible, the use of alternative linking facilities such as rail-guided vehicles for example which are cheaper and faster and which can also be regarded as possessing a potential for development and expansion when relevant standardization/modularization and conceptioning is provided,
- higher standardization degree in pallet use (ISO-norm)
- all in all a stronger modularization of systems; particularly as manufacturer of stand-alone machines and machining centres with a lower degree of integration so as to be able to leave the option open to the customer of being able to evolve towards a FMS by complementing these smaller units by additional components at some later date.

In the meantime, various flexible manufacturing facilities have become part of the production program of the company described here. A further integration of automatic systems into the company's own manufacturing process is planned and presently being realized.

b) FMS and Work Organization

The decision to staff the system with two operators was made at an early stage. Moreover, the wish to employ two equally qualified employees, who could replace each other had become more strongly voiced during the running-in phase. Six qualified operators would permit running the system in three shifts. However this could not be realized due to the lack of suitable employees. The up-grading of the qualifications of a second man to the level of the system leader was dispensed with in view of the initial difficulties running the system - greater priority was given to 'harmonious co-operation' within the pilot group, with each employee working to capacity on his job. Thus till date there is one differentiation between the system leader's tasks of managing system control, reading, testing, optimisation and correction of programmes, as well as pre-setting, and the palletizer's tasks of fixing/palletizing of workpieces. Apart from the division of functions to be observed between systems and areas outside of the system, this case study also demonstrates a relatively strong internal division of labour, which is only interrupted when there is an impasse in mounting and unmounting, as well as in setting (the view of the machine's working area necessary for certain supervision tasks is not given from the control bridge) and partially in setting tool fixtures.

According to the external division of labour which is oriented the existing company organization, the programming is carried out in the work planning department. An auxiliary department is responsible for providing tools within the entire manufacturing area for 'large casing parts' (20 machines). FMS servicing and maintenance is exclusively in the hands of special personnel. A central quality control department tests initial parts with regards to their dimensional accuracy.

In order to achieve optimal system utilization it was originally planned to carry out an extensive alteration of the shift system, with three partially overlapping shifts. This, however, could not be realized, as mentioned before, any less than a drawing out of the previous two-shift arrangement and an unmanned running of the third shift. The main reason was the tool magazine's limited capacity and - due to the relatively short running periods - considerable additional effort required for pallets and fixtures. the FMS' high productivity which caused capacity problems in other areas made an optimal running schedule less important. Moreover, the qualified, skilled workers employed in the system are hardly willing to accept extreme shift work.

In terms of wage systems, the solution favored by the company's management of incentive wages oriented to system availability (such as group premium pay) was also not to be realized because this might have endangered the piecework system level of an average of 170 % which had established itself on the FMS. Agreement was achieved concerning wage grouping. Due to his demanding position the system leader was placed into the wage group VIII (Metal Workers Wage Agreement, Bavaria). The palletizer, as well as the other machine operators in the manufacturing area for large parts, is working in a responsible position and placed in wage group VII.

c) Personnel Selection and Training

FMS staff was primarily selected by the foremen from the skilled workers employed in the area of large parts manufacturing. From the foreman's point of view, the basically good supply of skilled personnel is restricted by two aspects:

- Not all employees had the same amount of know-how and skills with regards to modern manufacturing technologies and

- not all employees consented to being transferred, voicing fears that the new job would be unusual and cause considerable nervous strain, while there was also uncertainty concerning the securement of the actual wages paid so far. Moreover, the ideal employees between 25 and 27 who are more open for the concepts of modern manufacturing technology and have also already gathered a certain amount of professional experience are, however, partially reserved towards extreme shiftwork and additional work tasks.

The policy of creaming off suggested by the former strategy is confirmed when one regards the choice of the first system leader, an 'absolute top employee'. The requirements set, which were then actually fulfilled, were stated by the foreman as follows: quick and reliable working in, no rejects, capability to cooperate, good professional qualifications (perfect reading of diagrams, good tool handling, expert tool knowledge), human qualities and low absence rates.

Apart from meticulous personnel selection, the necessity of which also resulted from the capacity for planning and improvising (no central computer!) required particularly in handling rush orders in between, the system leaders also took part in further training measures comprising an eight day programing course and a five day operator's course.

2.4 Case D

a) System Configuration and Company Framework Conditions

The FMS in case D is installed in a branch plant of a large-scale farm machinery enterprise employing approximately 750 persons. This plant manufactures the driving units.

The FMS, which consists of four machining centres linked by an automated guided vehicle, is used in the manufacturing of casing parts (approximately 50 variations at present). The system is run without system computer.

Introductory Process

The prime objective in installing an FMS was the drastic reduction of through-put times and the possibility of just-in-time manufacturing.

The manufacturing area in which the FMS has been installed previously handled batch sizes of 200 to 500 units on stand-alone machines carrying out 15 working processes and being run in two shifts. Some of these machines had to be replaced, but the decision was put off. The deadline of mid- '83 for government granted investment allowances in the Federal Republic of Germany provided the necessary incentive, however. The automation of the material flow was regarded as imperative for reducing the through-put time, therefore the alternative of stand-alone tool machines was not considered.

For the execution of the project a planning team was formed comprising plant manager (project leader), members of the work preparation department, foremen and leaders. The most important planning issue was the design of the information system. The installation of a system computer was finally dispensed with for reasons of cost. Automated guided vehicles were chosen as means of concatenation as this alternative granted better machine access.

The justification process compared FMS production with the alternative of obtaining the parts from other companies. The calculation of profitability also considered that the FMS offered the possibility of taking work, which for capacity reasons had been transferred elsewhere, back into the company's own manufacturing process. According to the plant manager the reduction of personnel costs was not decisive for FMS utilization, although eight members of staff were made redundant. Utmost priority was given to flexibility and reduction of through-put times due to the fact that manufacturing in the branch plant depends to 50 % on variations, the latter being determined exclusively by the customer and thus at very late date.

The scheduling of the planning process was determined by the last date of machine installation for which the investment allowance would still be granted (August 1983). Once the project's objectives were clarified, the works council and the employees were informed. The final choice of system manufacturer had not yet been made at this date, thus the works council and the employees had the chance of a certain degree of co-determination in this matter.

According to the plant manager the planning process ran an easier course than anticipated, and he stated that the fear of taking the first step, stirred up at many congresses, was worse than the actual process itself.

Experience with FMS Utilization and Further Planning

At the time of the survey the FMS had been running for about 2 1/2 years. After one year of operating an investigation of workplaces was carried out, the results of which led to numerous measures improving details which all in all had a considerable, positive influence on system availability. At date an availability of 80 % is given. System operators should not have to work to fullest capacity in order to have time for rush orders and creative spotting of possibilities to improve system running. There is general contentment with the form of work organization realized, whereby operating sequencing is to be more strongly integrated into the system in future. The number of casing variations manufactured on the system has increased from an original 24 to 53 at present, the processing times are between 20 minutes and one hour. The parts are manufactured within a variable part mix, there are 20 positions for intermediate storing so that employees are not bound to machine cycles.

A later calculation has shown that the FMS will have paid for itself in 2 1/2 years. Stocks were reduced by 7 % (in terms of value). Through-put time was cut from 12 weeks down to 10 days. Thus in summing up the opinion is held that FMS utilization has been worthwhile.

Accordingly further investments of this kind will be made within the plant. In the near future particularly the expansion of the existing FMS to seven machining centres is being planned. At the same time measuring equipment and a cell computer for system controll will be installed.

While it is generally intended to make use of computer control of the manufacturing process in future, the concept aimed for is not a centralistic one, but that of a network of cell computers, which independently take over transport control and the managing of orders. Operating sequencing and machine utilization planning is to be carried out by the operator by means of dialogue with the computer.

The utilization of further FMS is planned. A system comprising two machining centres and a broaching machine linked by a gantry crane system is to be installed in 1986. Moreover radial drilling machines are to be replace by seven machining centres, whereby the question as to whether, and if so, which means of linking will be used has not been clarified yet. The expansion of the machining centres to a system will be executed step by step.

A computer-aided PPS-system is in use in this company. This has not been operating to full satisfaction so that presently a better system is being looked for. A conversion is, however, impeded by the integration into the company group, which is using a CAD-system while there are no CAD-workplaces within the branch factory. CAD/NC linkage is not being planned so far.

At present about 70 % of the enterprise is organized as workshop manufacturing, the other 30 % as material flow oriented insular manufacturing. Developmental tendencies are more in the direction of an expansion of insular manufacturing, because this form of organization with its preconditions of
- formation of part families and
- material flow orientation

offers better possibilities for achieving just-in-time manufacturing with a reduction of through-put times and stocks.

b) FMS and Work Organization

The choice of FMS work organization must be viewed within the context of the overall company philosophy.

Previously, the company standard was work organization based on division of labour. It was noted, however, that standstill periods and repairs occurred more frequently and lasted longer in the case of certain machines, without being able to find actual technical reasons for this. A closer investigation of the phenomena gradually revealed that qualified and engaged operators contribute towards avoiding machine standstill and shortening fault finding times in case of repairs by their greater alertness and better technical communication with maintenance personnel, for example. Thus a gradual change in company thinking was set off towards structures based on less division of labour and more strongly oriented towards skills and qualifications.

According to the company maxim held today, no unskilled employee is allowed to operate a CNC-machine. The machine operator should have a knowledge of the entire operational sequence and possess a knowledge of machines and electronics. Thus work on the system was organized with relatively little division of labour. Programming, the tasks of manufacturing control, maintenance/repair as well as quality control of finished parts have, however, been excluded from the machine operators task spectrum. There are no differences concerning qualifications among machine operators, which means that they can replace each other when need be.

The FMS is run in three shifts, whereby the third shift is run fully staffed (with two operators). An unmanned, or lower staffed third shift is not regarded as possible due to the fact that tool control and measuring operations remain the same during the night shift because of the existing quality requirements. The alternative of manufacturing parts with larger processing times during the night shift is not viable because it would cause too much finishing work for the early shift.

Therefore FMS utilization left the operators with no other option but working in three shifts, whereby a daily change of shifts was opted for. A change of shifts every four weeks favored from the standpoint of industrial medicine was turned down by the employees on the grounds of the private problems resulting from such a solution. Otherwise FMS conversion caused no major problems.

An incentive to work on the FMS despite its running in three shifts is given by the wage system. The FMS employees are grouped according to work evaluation grade 29 of the regional wage agreement for North Rhine Westphalia (which corresponds to wage group 7-8) while operators in the other areas of manufacturing working at stand-alone machines are classed at work evaluation grade 22-23. There is no wage differentiation among FMS operators.

The employees are formally paid according to a piecework system which is, however, de facto more a time wage. The wage system is to be adapted to the actual conditions in the near future, although the high conversion expenditures still seem somewhat prohibitive at present. A form of premium wage is favored which would be oriented to system utilization and quality of manufacturing output.

c) Personnel Selection and Training

The personnel for the FMS operator team was, in the case of this company, also selected by pursuing a policy of creaming off. Six good, younger skilled workers (machine fitters) were already selected during the planning phase and were suspended from shift work in order to undergo a CNC basic training course. Resulting wage losses (shift allowances) were compensated for.

Finally the <u>four best</u> skilled workers were selected from the six having undergone training for FMS operating. During a second selection phase two more operators who had been previously working at the machines to be replaced were taken over as FMS operators. The remaining seven operators whose jobs had been replaced by the FMS were transferred to other jobs where they continue to work at stand-alone machines.

The FMS-operators took part in the following training measures directly related to their future work tasks:

a) Company external CNC-basic training at a local institute (duration approximately 12 weeks)

b) Training at the machine and control system manufacturer (one week)

c) On the job training directly on the system (approximately 10 weeks).

The external CNC-basic training accounted for approximately 1/4 of the total training expenditures. According to the plant manager's opinion this training reduces the period of time required to become familiar with FMS work from about 1 1/2 years down to approximately 1/2 year.

Today the company usually has a 'reserve' of two to three employers taking part in CNC-basic training on their own initiative, without being encouraged by the company or given financial support.

At present skilled workers account for 40 % of the company's personnel. The trend shows an increase and the company's aim is a future employment of 100 % skilled workers. The 'traditional skilled worker', however, is no longer in demand. The skilled worker of the future will be required to handle a greater amount of planning and self-regulating activities.

Manufacturing work in partially autonomous work groups with an increased shift of 'indirect' activities back into the area of production has caused less authority and competence to be held by foremen and leaders and has given rise to certain problems in this context. This hierarchical level will continue to decrease in future. This company is attempting to solve the problem by placing tasks of company training and further training in the hands of foremen, by entrusting them with the responsibility for the apprentices in the manufacturing area.

Vocational training in general is playing a greater part in the company again. The company in case study D is situated in a rural location, which means that a shortage of skilled workers still remains a problem despite of the altered general situation on the labour market. As the need for skilled workers in the manufacturing area is increasing due to the gradual changes in company philosophy previously described, apprenticeship training, which was discontinued in 1968, was resumed again in 1982. Presently training amounts to about 15 apprentices per year, under the care of a full-time training director. Furthermore, there are two employees in each manufacturing department assigned with the responsibility for apprentice training outside of the training workshop. These employees must have completed an in-plant trainers course which takes about 25 hours. Company training includes CNC knowledge during the second year.

Apart from this basic vocational training there are several further training offers such as courses in ergonomics for members of the work planning department and foremen and courses in machine-setting for machine operators (mainly for semi-skilled and un-skilled workers). Outside of the company it is mainly the courses for CNC-basics and technician training which are made most use of. The company's maintenance personnel attends courses offered by machine and control system manufacturers. Managerial personnel takes part in company external training (cost calculation, manufacturing control methods, work constitution act etc.).

2.5 Case E

a) System Configuration and Company Framework Conditions

The FMS examined in case study E is used in the manufacturing of precision casing parts. It consists of two machining centres, linked by an automatic guided vehicle. This vehicle also handels the material supply of five other manually operated machines, by transporting the workpieces back and forth between their automated storage and retrieval system (AS/RS) and the machines.

The FMS is installed in a machine building plant with 2.300 employees. The main plant we are dealing with manufacturers separators for the food industry. Smaller batch sizes, which are product group oriented and turned out on stand-alone machines are the norm for this plant. The export share is nearly 70 %.

Introductory Process

The FMS has replaced six NC-controlled unlinked boring mills which had become outdated. Several trips to Japan and visits to other companies planning or having installed FMS undertaken by the project leader (plant manager) gave impetus to the decision to install an FMS. Reducing stocks and batch sizes in the direction of just-in-time production was the objective pursued, thus there was no alternative planning. Apparently participation in the development of new technolgies and their utilization at an early date is also part of company tradition.

The planning team consisted of plant manager, two members of the work planning department as well as representatives of the companies supplying machines and transport system when required. Works council and employees were informed at the time of initial planning as the problem of transferring employees had to be dealt with.

None of the supplier companies acted as general contractor, the individual components being purchased independently instead. Therefore the planning teams main task consisted of coordination. The integration of the different computer and control systems used on the system was a further important area of planning. There were also problems of a more conventional nature to be solved such as the system's location for the vibration-free foundations necessary for running precision machines.

The choice of the machine manufacturer was quite conventional. The main criterion was whether the precision required in the micrometer area could be achieved or not. The manufacturer thus chosen, a supplier company of many years' standing, had to be persuaded to venture into the field of supplying FMS components. The choice of the transport system manufacturer was made on the grounds of the company's experience with linked manufacturing equipment and reference installations.

The transport system was given generous dimensions in order to be able to cope with future requirements. The two automatic guided vehicles are therefore not only used to supply the two machining centres belonging to the actual FMS, but also supply five other manually operated machines with material from the automated storage and retrieval system (AS/RS).

The FMS' information system consists of a central computer handling control data management and distribution (DNC-operating), transport control and order scheduling. Tool management has been integrated into the CNC-control systems. The information system's degree of automation was not explicitly planned, but can be regarded as having more or less 'evolved naturally'.

The part spectrum handled by the FMS was taken over without any alterations from the boring machines replaced and it comprises approximately 40 gear parts, each requiring two to three mountings during processing.

Experience Gained in FMS-Utilization and Further Planning

Contrary to the impression given during several congresses the planning phase of approximately two years, as stated by the project leader, was relatively short. While the system has been running since 1984 it is still too early to make any final statements on its availability, which at present is around 90 %.

Since then, no further calculations of profitability have been carried out. During the planning phase a comparison of profitability between the two systems, old and new, was carried out whereby it was presupposed that the FMS would run a third, unmanned shift. As this has been realized, it can be assumed that the system is economically efficient.

Apart from the FMS, the company has gained experience in the area of automatic transport and the fitting and loading of machines. The company strategy in these areas will be continued while integrating the experience gained with linking facilities - one would now, for example, no longer use a conventional gantry loader for a certain machining centre, but a model with a much larger operational range instead. A systematic, fully automated linking of several machines is no longer planned at present. Accordingly, a vertical turning cell with pallet exchanger and a machining centre with a pallet pool of three pallets are being planned, while several more machines will be supplied by an automatic transport system.

b) FMS and Work Organization

In this instance work organization was also not a special part of the planning procedure, but evolved mainly according to company tradition, whereby programming is carried out centrally by the work planning department (which presently spends 50 % of working time for FMS programming) and maintenance, as well as quality assurance are also centrally organized. Within the system, however, there is relatively little division of labour. Although the responsibility for the system running and the manufacturing control tasks are in the hand of the foreman, who works on the day shift, all other operations such as program testing, tool pre-setting and setting fixtures are managed by two employees during the first shift and one employee on the second. The unmanned night shift runs off more simpler parts with higher processing times. Eight intermediate storing places for mounting and unmounting suffice for one whole shift, whereby part processing times are between one and two hours. All three employees receive time wage (grade 9,5 between setter and leader) with various additional allowances, also for shift work, which places their wage level one to two grades above the surrounding manufacturing areas. System work meant wage improvement by about one grade for all persons employed there.

One of the further effects on other areas within the company to be mentioned was the necessity for the construction department to pay special attention to certain FMS- specific design-features.

c) Personnel Selection and Training

The form of work organization chosen demands relatively high system operator qualifications. Accordingly, employees were chosen who were regarded as 'willing to learn and to adapt'. The company's philosophy is to fill as many jobs as possible with company personnel. The qualification 'technician' was aimed for. This could not be attained, particularly due to the shift work involved, therefore skilled workers who had previously worked at stand-alone NC-machines and/or relief men have now been employed for FMS work. Only one of the employees came from the manufacturing area which was replaced by the FMS. The twelve persons previously employed in this area have been transferred to other areas and have retained their previous wage level. Thus in this case too, a policy of creaming off has been pursued.

This is also reflected by the extent of the training measures. The programmer and one operator participated in a one-week training course offered by the manufacturer. The two other operators received approximately two weeks of training on the system. Moreover there was a longer, independent running-in period on the system.

FMS personnel utilization must also be seen within the context of the company's overall qualification structure. 60 % of the 1.200 employees are skilled workers, a number of which are former semi-skilled workers who have 'only' received additional training. This personnel sector has been decreasing over the past four or five years, however. An independent training workshop, set off from the rest of the company trains approximately 50 apprentices per year.

3. Experiences out of Case Studies of Installed Flexible Manufacturing Systems

3.1 System Configurations in the Light of Different Company Structures

The companies investigated in the case studies (compare Table 9) all belonged to the mechanical engineering branch while the spectrum of products was most varied, encompassing driving and transmission components, farm machinery, manufacturing equipment and machine tools. The companies' sizes (number of employees) were also far from uniform, ranging from approximately 750 to about 13.000 employees. A positive economical development over the past years, as far as sales were concerned, was a common factor.

Table 9: Economic and Technical Informations about Analyzed Cases

	Case A	Case B	Case C	Case D	Case E
Branch	mechanical engineering (driving components)	mechanical engineering (driving components)	machine-tool industry	farm machinery	mechanical engineering (separators)
Number of employees	around 13,000	around 4,500	around 1,300	around 750	around 2,300
Year of FMS-installation	1983	1985	1983	1983	1984
Type of replaced manufacturing	transfer line	transfer line	unlinked machine-tools	unlinked machine-tools	unlinked machine-tools
Machining system	3 machining centers (MC)	8 MC	4 MC	4 MC	2 MC
Material flow system	rail-guided vehicle	conveyor belt	AGV	AGV	AGV
Information system	central computer	no central computer	no central computer	no central computer	central computer
Manufactured workpieces	gear boxes crankcases boxes for prototypes	axles	parts for machine-tools	gear boxes	gear boxes
Number of variants	around 40	around 40	around 20	around 50	around 40
Batch sizes	5 - 500	1 - 50	15 - 30	20 - 400	1 - 20
Processing time	12 - 180 minutes	15 - 25 minutes	10 - 100 minutes	20 - 60 minutes	60 - 120 minutes

While in all companies the immediate need for capacity expansion or impending replacement investments were the concrete reasons for FMS-installation, the situations given at the time of installation were quite varied: 2 companies replaced a transfer-line, in the other companies FMS took the place of stand-alone conventional and/or NC/CNC machine tools.

Accordingly, different aims were pursued by FMS installation. While companies replacing transfer-lines were mainly concerned with flexibly adapting to the neccessity of producing a rising number of variantes and to shorter product life cycles, the companies replacing stand-alone machine tools strove mainly to reduce through-put times, stock and work-in-process by means of production according to assembly requirements (JIT) in order to meet the shorter terms of delivery which the market demands.

As far as the planning process in the investigated companies was concerned, different focal points and problems arose which were mainly of a technical nature, resulting from machining requirements. Nevertheless, a certain amount of common ground was given. In all companies a planning team was formed which usually consisted of the FMS' promoter and members of the departments dealing with manufacturing planning and manufacturing respectively. An interdisciplinary planning team encompassing members of management, workers representatives and staff involved, for example, was not realised, however, due to the fact that planning was carried out by technicians in all cases. Thus the main emphasis of planning was on technical aspects, such as system layout, the FMS' spacial arrangement and the selection of machines (choice of manufacturer). Questions concerning job structures and training were given little consideration, while the criteria of the humanisation of work also played a subordinate role.

All companies carried out a calculatation of profitability in order to prove the FMS' profitability. This calculation, however, consisted solely of a comparison of manufacturing costs with the conventional type of manufacturing or with a make or buy calculation, due to the fact that an adequate calculation method for these complex systems does not exist to date. A comparison with the alternative of 'manufacturing based on stand-alone machining centres' was carried out in only one case. In this instance the increase achieved by FMS installation was negligible. The shortcomings of this form of calculation being well known, it provided only 50-60% of the justification procedure. Further important aspects are the acquiring of know-how with this new technology, long term increase in flexibility, reduction of through-put times and stock - all factors difficult or impossible to quantify. The criterion of 'saving labour costs'' played a subordinate role in the companies' planning considerations.

As far as the layout planning of the systems is concerned, one must differentiate between the planning of the machining system, the means of transport and the information system.

- The choice of machine types and their numbers was determined by the demands made on the machining of the parts spectrum as well as criteria pertaining to the specific manufacturers, such as their FMS experience, reliability, existing contacts, etc. The number of machines was determined by the capacity of the manufacturing equipment to be replaced, or also by the predicted capacity requirement in the case of expansion investments.

- As far as the choice of linking facilities is concerned, various strategies can be observed - in some cases the criterion of cost was given priority, while in others the aim was to be equipped for future, possibly altered demands to be made, thus leading to the installation of an interlinkage system utilizing automatic guided vehicles (AGV) and of far more generous dimensions than present demands would necessitate.

- The choice of the degree of automation of the information system (system computer) is not exclusively determined by functional criteria. In many cases the pilot character of the projects is stressed, the system users aim is to acquire know-how and experiment in the direction of computer-integrated manufacturing. Cases do exist, however, in which the installation of a central computer is refused for reasons of cost.

Although the systems investigated were all installed within the relatively short period between 1983 and 1985 and nearly all served the purpose of manufacturing prismatic casing parts, the technical design of the individual systems displayed a wide range of variations.

FMS have proved to be a form of technology which is gaining widespread acceptance in manufacturing. This is indicated by the fact that in all companies surveyed further FMS/FMC's are being planned or already run. Certain developmental tendencies can be discerned as far as these further plannings are concerned:

Firstly the trend to smaller systems recorded in the survey was further underlined. Where larger systems are being planned, they will be divided up into sub-systems which are mainly autonomous in terms of control and which will be loosely interconnected in terms of material and information flow. Furthermore, future systems are all to be equipped with computer control. It is planned, however, to also hierarchize the computer systems to a higher degree and de-centralize computer intelligence so that decisions can be made in system proximity (cell computer). An increased use is being made of the possibility of holding a dialogue with the computer, which means that the planning of machine utilization is not determined by a central computer, but can be influenced and optimized de-centrally on the system by a systems leader.

The flexibility to produce different workpieces which the systems prossess by the technical layout of the subsystems in a range of 20 - 50 variantes is utilized to different degrees in manufacturing practice. While at the one extreme these systems take over capacity requirement backlogs of parts otherwise machined on transfer-lines whose batch size are so large that a change over to another workpiece is only rarely required (every 2-3 days), in other cases an absolute part-mix is run off according to assembly requirements.

The degree of the flexibility, the systems display in terms of adaptation, meaning the extent of setting operations required when changing over to a new workpiece, is also subjects to variations. Considerable differences also exist as regards machining redundancy and freedom of machine utilization, that is whether processing is carried out in one or several steps. Definite, clear-cut developmental trends as far as system flexibility is concerned do not stand out at present.

3.2 Variation of Job Structures

A comparison of the cases of FMS and FMC use which were investigated in detail shows clearly that a uniform concept for forms of job structures, division of labour and manpower utilization in the metal-processing industry in the Federal Republic of Germany has yet to take place. All in all, a great deal of variety can be observed in the way that tasks still in existence despite automation are focused on jobs for workers who are more or less continuosly attached to the system, but also in the way these tasks are defined as far as the functions of departments not involved in the actual manufacturing process are concerned. Certainly this variability has partially to do with the differences existing between the individual systems in terms of their size, machine configuration, degree of automation and the characteristics of the given manufacturing process etc.; it is apparent, however, that the scope for design is utilized to varying degrees according to the conditions prevailing within the company and the particular goals pursued. Differences concerning the division of labour in personnel utilization can be perceived on two levels:

- On the one hand the question is whether the personnel directly attached to the system is employed within a homogeneous job structure performing tasks of the same type, or is allocated to inhomogeneous jobs on which different demands are made and different, complementary functions are to be performed.

- On the other hand there is the definition of the 'points of intersection', often termed as indirect functions within the company, which in the past, under the influence of Tayloristic organisational principles, had often been marked off from the task scope of the shop floor personnel and assigned to departments of their own. These functions can be integrated into the task scope of the shop floor personnel in varying degrees.

The cases more closely examined were all situated between the two conceivable extreme types of system operator employment combined with a high degree of division of labour and a considerable significance of system external intervention on the one hand, and a largely autonomous group of system operators with a homogeneous training level on the other, who run the system largely independently, quasi as a 'factory within the factory', whereby responsibility is shared and jobs and tasks performed in turn if necessary.

In many cases the period of system use is still too short for much experience to have been gained and forms of job structures and manpower utilization to have become firmly established. In some cases practical experience of system use leads to altered job structures, as was the case in a company where the very differentiated job structures originally prevailing were replaced by a far less differentiated division of labour (case A).

In some cases there are also plans for an extensive re-organisation of job structures in connection with large scale installation of flexible manufacturing technolgy. Here it is intended to de-centralize functions such as work scheduling, programming, quality assurance, control of production flow etc. and to attach them more closely to personnel engaged in the various individual areas of the production apparatus, or to integrate them into manufacturing shops for specific parts families. At present it remains to be seen whether, and to what extent such concepts will find wider acceptance and according to what guidelines tasks and jobs will be assigned within such system teams where a wider distribution of responsibility is given.

There are also differences in the type of shift work prevailing in flexible manufacturing cells and systems. Usually the systems are run in two shifts, whereby a tendency towards extension of utilization times can be observed throughout, and certain beginnings of dissociation of system utilization and personnel employment periods are gradually taking on shape. Not in all cases the running of a third partially unmanned or lowly staffed shift is regarded as meaningful or practical. Apart from cases of varying numbers of employees working on different shifts, there is also the practice of running three shifts with the same number of workers per shift (case D).

Table 10: Division of Labour and Job Assignment in Five FMS-Cases

Tasks and Functions	Case A				Case B			Case C			Case D		Case E	
	FMS-external	FMS-internal job I	job II	job III	FMS-external	FMS-int. job I	job II	FMS-external	FMS-int. job I	job II	FMS-external	FMS-internal job I	FMS-external	FMS-internal job I
- programming	x				x			x			x		x	
- program optimisation	x		x		x	x			x			x		x
- operating sequencing		x			x			x			x		x	
- (pre)setting of tools				x	x	x		x				x		x
- loading of tool magazines			x			x			x	x		x		x
- overall FMS-responsibility		x	x		x	x			x			x	x	
- (re)setting of fixtures			x				x		(x)	x		x		x
- fixing of workpieces (palettizing)			x				x		(x)	x		x		x
- setting of machine tools			x			x			x	x		x		x
- supervising of operations			x			x			x			x		x
- in-process quality assurance			x			x			x			x		x
- final inspection of processed components	x		x		x			x			x		x	
- maintenance routine	x				x			x			x	x	x	
- minor repairs			x		x	x	(x)	x				x		x
- major maintenance and repairs	x				x			x			x		x	
Number of Workers per shift														
1. shift		(1)	2	(1)		1	2		1	1		2		2
2. shift		0	2	(1)		1	2		1	1		2		1
3. shift		-	-	-		-	-		-	-		2		0
Job/Tasks Assignment														
- fixed									x	x				
- open			x				x					x		x
- job rotation						x								
Qualification Structure (number of workers)														
- foremen/technicien		1												
- skilled worker			4	2		9			2	2		6		3
- semi-skilled worker														
Initial Training of Staff (duration in weeks)														
- FMS manufacturer's training courses		16	2			2						1		2
- off-the-job training		-	-	-					2			12		
- on-the-job training		24	24			6			24	6		10		8

3.3 Recruiting and Training

The methods used in recruiting personnel for the flexible manufacturing systems and manufacturing cells and in preparing them for the tasks to be fulfilled are relatively similar among the companies investigated.

In most cases younger, experienced workers who are regarded as willing to learn and adapt are 'creamed off' the reservoir of existing manufacturing personnel. This usually is done before the system is installed so that employees can take part in training courses offered by systems manufacturers and can subsequently participate in building up the system. In some cases special training courses are mandatory (programming, use of CNC for example) which are either held by the user companies' training departments or elsewhere.

To the greatest extent, skilled workers who had an apprenticeship in a metal-processing trade, are employed. Due to altered labour market conditions the companies face fewer problems in finding skilled workers for the jobs in manufacturing, even if they are connected with the disadvantage of shift work. This is particularly the case with young skilled workers who more recently concluded apprenticeship and training and are therefore better skilled in modern controlling and machining technologies than their older colleagues are.

In none of the companies surveyed flexible manufacturing systems are installed to such an extent that these recruiting methods would begin to deplete the potential skill reserves within the given company itself. It remains a different question however, whether within the framework of extensive technical and organisational innovation measures an extensive re-organisation of the manufacturing workforce from the present semi-skilled to a skilled status could be established and what expenditures would be necessary to this end. On the one hand stagnating employment in the companies hardly allow a change in the skill structure by means of exchange processes with the external labour market. On the other hand though, the companies' training departments are seldom prepared to train larger numbers of semi-skilled workers in a manner suited to adults.

SUMMARIZING AND CONCLUSION

The investigation has shown that flexible manufacturing systems and flexible manufacturing cells have gained considerable significance compared to their state of development a few years ago. By the end of 1985 there were approximately twice as many such systems in the Federal Republic of Germany as there were in 1983. In 1985/86 there will be an estimated 200 flexible manufacturing cells and 100 systems encompassing several machines. The dissemination process of flexible manufacturing cells is more dynamic than that of systems encompassing several machines. As far as the flexible manufacturing systems in the closer sense of the word are concerned, those systems encompassing several machine tools and possibly other aggregates, a certain trend towards smaller system units is notable. Where at present very large systems with 20 or more machines are still being planned, these are to be divided up into smaller subsystems (encompassing 3-7 machines) which are mostly autonomous and tend to be loosely interlinked as far as material and information flow is concerned.

With regards to information systems the utilization of a central system computer is now frequently dispensed with in favour of a less elaborate, more decentral design of the information and control system. Future systems encompassing several machines will usually be equipped with a system computer; however, a more strongly hierarchical computer configuration with decentralized computer intelligence is planned so that it becomes technically possible for the system operators to make decisions decentrally (concerning the planning of machine utilization for example) by means of interactive communication.

The majority of machine tools integrated by the systems are machining centers; lathes and special machines play an important part in larger systems. The choice of linking equipment for workpiece and tool transport as well as their handling depends mainly on system size and machine configurations; therefore general developmental trends can hardly be discerned in this area.

The majority of the systems (85 %) takes over production tasks which were previously handled by stand-alone conventional machines or NC-machines; only 11 % of the systems replace transfer-lines, that is, highly automated, but rigid manufacturing systems. Thus the innovation objectives of increasing productivity and reducing through-put times were of greater significance than increasing flexibility to cope with a larger number of variations in the manufacturing area.

Medium and large-scale enterprises (with 500 employees and more) in engineering industries are the main field of FMS-utilization. For most companies system utilization (still) has the character of a pilot project. Nevertheless it can safely be assumed that flexible manufacturing systems and cells are an important technological line of development, namely one of the components of the increasing computer-aided integration with which the companies are trying to realize or expand manufacturing concepts which have been termed as 'the factory of the future'. Apart from this, other possibilities of technical innovation are being pursued, partially as a parallel strategy, in other cases as a complementary course, which come under the heading of computer-integrated manufacturing (CIM), such as computer-aided design and computer-aided manufacturing (CAD/CAM), extended DNC-utilization, as well as new systems of production planning and production control (CAPM) etc.

While flexible manufacturing systems and cells had spread rather slowly up until the beginning of the 80's, they are now undoubtedly an important line of technical development and their effects on work organization and manpower policy require closer analysis. At present, however, it is difficult to judge future developments on the grounds of the experience gained so far, due to this specific period of transition and the fact that many companies are still experimenting with these new manufacturing technology components.

The investigation findings presented here demonstrate clearly once again that there are no deterministic connections between the systems' technical design, the solution chosen for work organization and manpower utilization and the type and extent of training measures subsequently resulting from these technical innovations. It is apparent that individual companies with their specific framework conditions make different use of similar manufacturing equipment. This shows that it is possible to adapt and design technology according to different company and employee requirements (particularly the information system's control software, but also in terms of operator convencience). But a systematic improvement of working conditions by introducing forms of work organization based on less division of labour for example, has been attempted by relatively few companies so far.

The form of work organization opted for is in reality not so much determined by imperatives of the manufacturing-technology but more by the traditional structures within the companies themselves. In many companies this means an orientation towards forms of work organization and manpower utilization based on a high degree of division of labour. Particularly when the issue of division of labour between system team and the areas of planning, control and supervision is to be determined, then existing structures of company organization with separate departments for work planning, maintenance and quality assurance will tend to favor system external performance of functions such as programming and optimisation, production control, correction of system failures or the quality inspection of manufactured workpieces. Also the share of flexible manufacturing systems and flexible manufacturing cells with a strong internal division of labour, i.e. where several specialized jobs have been defined for workers with different qualifications, is larger (although only marginally) than those systems organized on a lesser degree of division of labour.

The case study findings, however, do point towards an increasing recognition of the advantages of more comprehensive forms of work and the utilization of skilled workers in connection with new manufacturing technologies installed in the companies.

- In view of the still comparatively high costs of flexible manufacturing technology, the argument of reducing wages and labour costs plays a relatively minor role. The differences in wage costs between specialized semi-skilled workers on the one hand and comprehensively qualified skilled workers on the other are negligible when compared to the high machine rates per hour.

- In a number of cases the experience was made that problems concerning insufficient availability of complex manufacturing systems were only seemingly of a solely technical nature and proved also to have to do with the forms of manpower utilization opted for. Larger system operating teams with comprehensive training can prevent system failure and breakdown periods by expert and timely intervention.

- Vacancies are easier to compensate for when all system operators are capable of performing all required tasks and can therefore take each other's places if need be.

- Finally, due to the altered labour market situation in the past years, many companies have less difficulties in recruiting skilled workers, particularly younger skilled workers who are often more familiar with modern manufacturing technologies, provided that reasonable working conditions and wages are given. This even holds true in cases where more shift work must be accepted.

The limits and stability of such forms of work organization and manpower utilization cannot be clearly defined at the moment. While their dissemination is furthered by their obvious advantages for the company and employees on the one hand, the perseverance of traditional structures and principles of manpower policy must not be underestimated, which in many companies are oriented to a strong division of labour and a strong supervision of job performance.

This is an area which definitely requires further research. A substantiation of the above mentioned connections would be an important task, particularly during this present early phase of dissemination of flexible manufacturing systems and cells, in order to prove to the companies that the 'investment' in more human job structures and the retention of skills and qualifications in the immediate vicinity of the manufacturing process is indeed a 'profitable' one. Moreover, it must not be forgotten that the conditions presently observed within the companies are often strongly influenced by the special situation arising during the introduction of new technologies in which uncertainties are evident and which is characterized by company experimentation.

A definite trend in work design in the area of flexible manufacturing systems and flexible manufacturing cells is not yet discernable. Within the entire field of companies having more or less longer experience with new manufacturing technology the forms of work organization and manpower utilization differ widely and in individual cases several revisions of organizational principles have occurred.

Moreover, in many cases in which new systems have been installed there have been no definite improvements in working conditions for the personnel immediately affected. Apart from the previously stated trend towards increased shift work and new forms of work burdens and stress factors in a more open work situation, this also has to do with the specific forms of recruiting personnel for the new jobs. In almost all cases a strategy of 'creaming off' has been pursued, i.e. workers are recruited from the internal labour market who appear to be particularly well qualified and suited and who have gathered experience in similar work situations in other parts of the company. The need for additional training is recognized by many companies. In most cases, however, this remains restricted to comparatively short training courses offered by the companies supplying machines or control systems and to the process of 'learning by doing'. Comprehensive and compensatory training of manufacturing workers for their new jobs and tasks is very rarely undertaken. In almost all cases the flexible manufacturing systems so far installed form small 'islands' within the companies' manufacturing apparatus and therefore the policy of minimizing training expenditures has been quite successful so far, as it has not (yet) exhausted the existing qualification reserves. This question will gain another dimension in the near future, however, when flexible manufacturing systems will lose their pilot character and -in connection with other computer-aided technologies - find widespread use.

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