





Proceedings of the 4th  
International Conference on

# **FLEXIBLE MANUFACTURING SYSTEMS**

**15th ~ 17th October 1985,  
Stockholm, Sweden**



**Edited by  
R. Lindholm**

An international event organised and sponsored  
by IFS (Conferences) Ltd, Kempston, Bedford, UK

Co-published by: IFS (Publications) Ltd and North-Holland  
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# Proceedings of the 4th International Conference on FLEXIBLE MANUFACTURING SYSTEMS

The FMS-4 Conference took place concurrently with  
the 3rd International Conference on **Automated Guided Vehicle Systems** and  
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IFS (Conferences) Ltd would like to acknowledge the cooperation of Citroën Industrie, UK in permitting the layout diagram for the Meudon plant FMS (France) to be used in the Proceedings cover design.

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Jointly published by:

**IFS (Publications) Ltd, UK**  
35-39 High Street, Kempston, Bedford MK42 7BT, England  
ISBN 0-903608-97-9

**North-Holland** (a division of Elsevier Science Publishers BV)  
PO Box 1991, 1000 BZ Amsterdam, The Netherlands  
ISBN 0-444-87814-9

*In the USA and Canada:*  
Elsevier Science Publishing Company Inc  
52 Vanderbilt Avenue, New York, NY 10017

Printed by Cotswold Press Ltd, Oxford, UK

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## FOREWORD

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FMS-4 Conference Chairman:  
**R. Lindholm**  
President, The Swedish Management Group

**F**MS is a truly cross-disciplinary subject requiring skills and knowledge from several specialities to be merged together in order to make possible the development of a competitive manufacturing system.

FMS is an important technology for a country like Sweden with a small domestic market in the respect that the advantage of large scale production is reduced by this new technology. Swedish companies can become more competitive on the international market. The Swedish car manufacturers are good examples of this.

The state-of-the art of Flexible Manufacturing Systems is still dominated by a few forerunning companies but it is evident that the technology has now reached a state where it can be put to profitable use by a large number of companies. This is also reflected in the diffusion of the technology which is very rapid today.

In order to further this development it is in my opinion necessary to focus more on the skills and prerequisites required to design, introduce and operate FMS in 'ordinary' companies. One obstacle is the economic justification which must take into account far more than the labour saving effects in order to make the system pay-off. It is also important to find practical solutions to upgrading the operator-skills, developing new work forms and integrating the FMS into the company environment as a whole. Furthermore must wageforms, planning methods, methods for measuring results and local-area information be developed.

The development and experience of FMS in Sweden have to a large extent their roots in efforts to improve work environment and untie operators from machine paced work in order to utilize both capital equipment and human skills better. Due to this there are a large number of companies in Sweden with a very good basis to adopt the FMS technology and we already have many embryos to genuine FMS in operation in the form of partly or completely automated manufacturing cells. One more national strength is the recently signed 'Agreement on efficiency and participation' between the major labour market organizations SAF, LO and PTK. This agreement states shared values on adopting new technology to promote efficiency and participation and outlines ways to cooperate in the firms in practical and flexible ways giving the individual employee better opportunities to influence his working-conditions.

Sweden is for the first time host for the international conference of Flexible Manufacturing Systems – the fourth so far – and this is a great opportunity for us to share experiences in the FMS field with colleagues from other countries for mutual benefits.

Finally I would like to thank the programme committee for its valuable support in arranging the conference.

ROLF LINDHOLM.

# CONTENTS

ORIGINAL PAGE IS  
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## FMS International Overview

<b>FMS – Research Viewpoint</b>	
H.-J. Warnecke, Fraunhofer Institute for Production Automation (IPA), West Germany	1
<b>Trends in advanced manufacturing technology</b>	
B. Weichbrodt, Asea Robotics, Sweden	13
<b>Operation of the flow type FMS</b>	
H. Yamashina, K. Okamura, Kyoto University and K. Matsumoto, Nippon Denso Co Ltd, Japan	15
<b>Putting the 'S' in FMS: The key word is system</b>	
D. B. Ewaldz, Ingersoll Engineers Inc, USA	27

## Swedish Experience in FMS

<b>FMS and automation in a diesel engine plant</b>	
R. Murby, Volvo Components Corporation, Sweden	43
<b>FMS applications with industrial robots for short machine cycles</b>	
G. Martins, ASEA AB, Sweden	49
<b>Frame drilling at the Scania plant – a flexible, high-performance production system</b>	
K. Holmélius, Saab-Scania AB, Sweden	57

## FMS at Work

<b>FMS for plastic working in Japan</b>	
J. Endow, Tokyo Institute of Technology; M. Kiuchi, University of Tokyo; K. Nakazawa, Mechanical Engineering Laboratory; M. Shinohara, Tokyo Metropolitan University and S. Matsubara, The Institute of Vocational Training, Japan	69
<b>CIM – A case study of the successful Allen-Bradley contactor/starter line</b>	
P. N. C. Cooke and A. Pascaru, Allen-Bradley International Ltd, UK	81
<b>New developments in FMS, CAD/CAM and PM integration</b>	
M. Dub, Research Institute of Engineering Technology and Economy (VUSTE), Czechoslovakia	89
<b>Flexible manufacturing system in operation</b>	
R. C. Findlay, Giddings & Lewis Manufacturing Systems, UK	99
<b>Ferrari Auto: An FMS of the latest generation designed to resolve the machining problems of one of the most sophisticated car industries</b>	
P. Egalini and A. Ferrari, Mandelli SpA, Italy	107
<b>The evolution of FMS at Volvo Components Corporation in Skövde</b>	
G. Nordsten, Volvo Components Corporation, Sweden	125
<b>Flexible assembly systems with pneumatically-actuated robots in instrument-making industry</b>	
I. P. Mitjashin, A. N. Chernichin and Y. V. Shabrikhin, Minpribor, USSR	135

## FMS – The Technological Resources

<b>Laser cutting – FMS cell with a future</b>	
I. Lilja, Valmet Corporation, Finland	147
<b>Abrasive water jet – a new technology</b>	
J. Gerin Sylvia, University of Rhode Island, USA	157
<b>Compensating for inherited error in FMS</b>	
Cai Li Jun, Yuan Zhe-Jun and Zhang Yong, Harbin Institute of Technology, China	167
<b>Different techniques for automatic identification in FMS installations</b>	
J. Lindgren, Saab Automation AB, Sweden	175
<b>In-process dimensional inspection of truck cabs with measuring robot</b>	
S. Gunther-Hanssen, ASEA Robotics, Sweden	179
<b>Cutting tool development for automation and FMS</b>	
A. Cederqvist, AB Sandvik Coromant, Sweden	187

## The Crux of FMS – Low Volume/High Variety Production

<b>The cell formation problem in flexible manufacturing systems</b>	
S. P. Dutta, R. S. Lashkari, A. Padhye, G. Nadoli and T. Ravi, University of Windsor, Canada	199
<b>FMS in a high variety small batch environment</b>	
M. W. Looney, Inbucon Management Consultants Ltd, UK	209
<b>An FMS for high variety – short cycle time components</b>	
M. C. Evans, Pegler-Hattersley plc, UK	215
<b>Flexible automated manufacturing of flat sheet metal components in low quantities</b>	
M. Benzinger and B. Andrae, Trumpf Systems Engineering GmbH, West Germany	239
<b>British Aerospace: small machined parts: Flexible manufacturing system: A case study</b>	
M. Goulding, British Aerospace plc, UK	257
<b>Flexible machining centre for big components</b>	
R. Petersen, AB Bygg-och Transportekonomi (BT), Sweden	269
<b>FMS – a welding cell</b>	
M. Annborn, AB Bygg-och Transportekonomi (BT), Sweden	279



# Management and Control of FMS – A Review of Principles and Systems

<b>A computer based control system for flexible assembly lines</b>	
D. Testa, A. Vettori, Centro Ricerche Fiat and F. Corradini, A. Naso, Fiat Trattori, Italy	293
<b>FMS control strategy – a survey of the determining characteristics</b>	
J. S. Edghill and C. Cresswell, University of Wales Institute of Science and Technology, UK	305
<b>Implementing FMS – planning for CIM or creating 'Islands of automation'</b>	
B. Klemming, IBM, Sweden	317
<b>Strategy-based interactive production control for flexible automated systems</b>	
G. Spur and K. Mertins, Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK), Berlin, West Germany	329
<b>Choice of control system for FMS-cells with aspect of economy and reliability</b>	
J.-E. Elfving, SattControl AB, Sweden	341
<b>Flexible control systems for flexible manufacturing systems</b>	
N. R. Greenwood, General Electric Industrial Automation (Europe), UK	349

## FMS – Practice and Experience

<b>Implementation of mechanized manufacturing cells in an existing production as an economical alternative to FMS (a case study)</b>	
M. Chakraborty, AEG-Telefunken, West Germany	357
<b>Flexible grinding system for gas turbine blades</b>	
E. Ramsli, T. K. Lien, NTH-SINTEF and T. Gosling, A/S Kongsberg Våpenfabrikk, Norway	369
<b>A case history of FMS introduction in aerospace aircraft sheet metal detail manufacture – 'A time for change'</b>	
G. K. Harbert and R. A. Sams, Westland Helicopters Ltd, UK	379

## Systems Analysis and Design

<b>Methods for simplification of flexible manufacturing production system complex</b>	
S. Hjelm, IVF/KTH, Sweden	397
<b>Conclusions from simulation of small and large FMS projects</b>	
H.-J. Warnecke, R. Steinhilper and K.-P. Zeh, Fraunhofer Institute for Production Engineering and Automation (IPA), West Germany	409
<b>Validation of a modern FMS simulator</b>	
P. L. C. Dunn, Citroën Industrie, UK	425
<b>Simulation in the area of sheet bending parts</b>	
J. Triouleyre, Ecole Nationale Supérieure d'Arts et Métiers, France	433
<b>An innovative FMS for automotive mechanical components</b>	
P. Vicentini and A. Gambini, Alfa Romeo SpA, Italy	439
<b>Case study: design of an FMS for producing TV tuners</b>	
W. S. Yu and N. C. Ho, Nanyang Technological Institute, Singapore	451

## FMS – Strategic Considerations

<b>Some technical, operational and human aspects of manning FMS</b>	
R. G. Hannam, University of Manchester Institute of Science and Technology (UMIST), UK	459
<b>Manufacturing information systems for FMS</b>	
P. Weill, Royal Melbourne Institute of Technology, Australia	467
<b>Profitable flexible manufacturing systems</b>	
P. Foyer, Ingersoll Engineers Inc, UK	483

## Supplementary Paper

<b>Design and simulation software for flexible assembly systems</b>	
P. G. Ranky, ITI, University of Michigan, USA	507

## Late Papers

<b>Planning system and work organisation in flexible manufacturing systems</b>	
B. Samlin, PMC Consult, Sweden	521
<b>Automated guided vehicles in FMS: a review of current technology</b>	
A. Shuttleworth, Schindler-Digitron AG, Switzerland	525
<b>Computer integrated and automated manufacturing systems in aircraft manufacturing – user's viewpoint</b>	
G. Handke, MBB-Automation Technology Division, West Germany	533
<b>FMS at Atlas Copco Avos, Örebro – practice and experience</b>	
B. Håkansson, Atlas Copco MCT AB, Sweden	559
<b>Mid-high volume random FMS for clutch and drive gearboxes of various types for tractors (Fiat Trattori, Italy)</b>	
S. Romanini, Comau, Italy	563
<b>Case study of the design and installation of a robot-loaded machining cell</b>	
G. M. Hull, Cincinnati Milacron Ltd, UK	575

# AUTHOR INDEX

- B. Andrae** ..... 239  
Trumpf Systems Engineering GmbH, West Germany
- M. Annborn** ..... 279  
AB Bygg-och Transportekonomi (BT), Sweden
- M. Benzinger** ..... 239  
Trumpf Systems Engineering GmbH, West Germany
- Cai Li Jun** ..... 167  
Harbin Institute of Technology, China
- A. Cederqvist** ..... 187  
AB Sandvik Coromant, Sweden
- M. Chakraborty** ..... 357  
AEG-Telefunken, West Germany
- A. N. Chernichin** ..... 135  
Minpribor, USSR
- P. N. C. Cooke** ..... 81  
Allen-Bradley International Ltd, UK
- F. Corradini** ..... 293  
Fiat Trattori, Italy
- C. Cresswell** ..... 305  
University of Wales Institute of Science and Technology, UK
- M. Dub** ..... 89  
Research Institute of Engineering Technology and Economy (VUSTE), Czechoslovakia
- P. L. C. Dunn** ..... 425  
Citroën Industrie, UK
- S. P. Dutta** ..... 199  
University of Windsor, Canada
- J. S. Edghill** ..... 305  
University of Wales Institute of Science and Technology, UK
- P. Egalini** ..... 107  
Mandelli SpA, Italy
- J.-E. Elfving** ..... 341  
SattControl AB, Sweden
- J. Endow** ..... 69  
Tokyo Institute of Technology, Japan
- M. C. Evans** ..... 215  
Pegler-Hattersley plc, UK
- D. B. Ewaldz** ..... 27  
Ingersoll Engineers Inc, USA
- A. Ferrari** ..... 107  
Mandelli SpA, Italy
- R. C. Findlay** ..... 99  
Giddings & Lewis Manufacturing Systems, UK
- P. Foyer** ..... 483  
Ingersoll Engineers Inc, UK
- A. Gambini** ..... 439  
Alfa Romeo SpA, Italy
- J. Gerin Sylvia** ..... 157  
University of Rhode Island, USA
- T. Gosling** ..... 369  
A/S Kongsberg Våpenfabrikk, Norway
- M. Goulding** ..... 257  
British Aerospace plc, UK
- N. R. Greenwood** ..... 349  
General Electric Industrial Automation (Europe), UK
- S. Gunther-Hanssen** ..... 179  
ASEA Robotics, Sweden
- R. G. Hannam** ..... 459  
University of Manchester Institute of Science and Technology (UMIST), UK
- G. K. Harbert** ..... 379  
Westland Helicopters Ltd, UK
- S. Hjelm** ..... 397  
IVF/KTH, Sweden
- N. C. Ho** ..... 451  
Nanyang Technological Institute, Singapore
- K. Holmelius** ..... 57  
Saab-Scania AB, Sweden
- M. Kiuchi** ..... 69  
University of Tokyo, Japan
- B. Klemming** ..... 317  
IBM, Sweden
- R. S. Lashkari** ..... 199  
University of Windsor, Canada
- T. K. Lien** ..... 369  
NTH-SINTEF, Norway
- I. Lilja** ..... 147  
Valmet Corporation, Finland
- J. Lindgren** ..... 175  
Saab Automation AB, Sweden
- M. W. Looney** ..... 209  
Inbucon Management Consultants Ltd, UK
- S. Matsubara** ..... 69  
The Institute of Vocational Training, Japan
- K. Matsumoto** ..... 15  
Nippon Denso Co Ltd, Japan
- G. Martins** ..... 49  
ASEA AB, Sweden
- K. Mertins** ..... 329  
Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK), Berlin, West Germany
- I. P. Mitjashin** ..... 135  
Minpribor, USSR
- R. Murby** ..... 43  
Volvo Components Corporation, Sweden
- G. Nadoli** ..... 199  
University of Windsor, Canada
- K. Nakazawa** ..... 69  
Mechanical Engineering Laboratory, Japan
- A. Naso** ..... 293  
Fiat Trattori, Italy
- G. Nordsten** ..... 100  
Volvo Components Corporation, Sweden
- K. Okamura** ..... 15  
Kyoto University, Japan
- A. Padhye** ..... 199  
University of Windsor, Canada
- A. Pascaru** ..... 81  
Allen-Bradley International Ltd, UK
- R. Petersen** ..... 269  
AB Bygg-och Transportekonomi (BT), Sweden
- E. Ramsli** ..... 369  
NTH-SINTEF, Norway
- P. G. Ranky** ..... 507  
ITI, University of Michigan, USA

<b>T. Ravi</b> .....	199	<b>P. Vicentini</b> .....	439
University of Windsor, Canada		Alfa Romeo SpA, Italy	
<b>R. A. Sams</b> .....	379	<b>H.-J. Warnecke</b> .....	1,409
Westland Helicopters Ltd, UK		Fraunhofer Institute for Production Automation (IPA), West Germany	
<b>Y. V. Shabrikhin</b> .....	135	<b>B. Weichbrodt</b> .....	13
Minpribor, USSR		ASEA Robotics, Sweden	
<b>M. Shinohara</b> .....	69	<b>P. Weill</b> .....	467
Tokyo Metropolitan University, Japan		Royal Melbourne Institute of Technology, Australia	
<b>G. Spur</b> .....	329	<b>H. Yamashina</b> .....	15
Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK), Berlin, West Germany		Kyoto University, Japan	
<b>R. Steinhilper</b> .....	409	<b>W. S. Yu</b> .....	451
Fraunhofer Institute for Production Automation (IPA), West Germany		Nanyang Technological Institute, Singapore	
<b>D. Testa</b> .....	293	<b>Yuan Zhe-Jun</b> .....	167
Centro Ricerche Fiat, Italy		Harbin Institute of Technology, China	
<b>J. Triouleyre</b> .....	433	<b>K. P. Zeh</b> .....	409
Ecole Nationale Supérieure d'Arts et Métiers, France		Fraunhofer Institute for Production Automation (IPA), West Germany	
<b>A. Vettori</b> .....	293	<b>Zhang Yong</b> .....	167
Centro Ricerche Fiat, Italy		Harbin Institute of Technology, China	

## Late Papers

<b>B. Håkansson</b> .....	559	<b>S. Romanini</b> .....	563
Atlas Copco MCT AB, Sweden		Comau, Italy	
<b>G. Handke</b> .....	533	<b>B. Samlin</b> .....	521
MBB-Automation Technology Division, West Germany		PMC Consult, Sweden	
<b>G. M. Hull</b> .....	575	<b>A. Shuttleworth</b> .....	525
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## FMS - Research Viewpoint

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### Abstract

After an initial hesitation flexible manufacturing systems have now begun to prove themselves as economical aids in solving demanding and variegated manufacturing problems, particularly in the increasingly important small and medium batch production area. Encouraged by the more than ten years of intensive research and various pilot projects in this field, the number of systems installed has recently grown in leaps and bounds.

Even now that the breakthrough in practice appears to have come about, however are still a large number of research tasks waiting to be dealt with. These include the solution to the problem of existing flexibility bottlenecks, particularly with regard to machine periphery, and also the development of more efficient universal systems software for organizing and monitoring the increasingly complex machining and material flow functions.

In addition the horizontal and vertical integration of flexible manufacturing systems in the overall production process in a consistent manner, together with an increase in flexibility and productivity of parts manufacturing in other prior and subsequent areas, will also have to be looked into in greater detail in the future. Developments here are tending in the direction of uninterrupted connection of all operating areas with individual activities coordinated and monitored with the aid of a hierarchically designed computer structure.

## **1 FMS - an integral part of a new production philosophy**

The market for many industrial goods has now become a buyer's market and the profitability of a company is no longer determined by output or turnover alone. On the contrary survival for a lot of firms depends on reacting more flexibly and adapting more rapidly to customer requirements. "The customer is always right" and it is he rather than the manufacturer who determines the course of events. For industrial companies this means coming to terms with the idea of greater product and part diversification, higher quality demands and shorter product development and delivery periods. It also means that the prevailing idea of high productivity must be supplemented by that of greater flexibility. Industrial concerns will have to improve the service aspect of their operations and guarantee rapid order processing through flexible staffing and excess operating capacities. The constant struggle in production companies against product diversification only has limited prospects of success because the market is simply more powerful. We must therefore attempt to structure our products so as to be able to respond to the idea of product diversification in as economical way as possible.

One method of achieving this is the use of highly automated yet flexible systems for parts production. With the increasing use of such methods the entire philosophy of production is undergoing a change, marked by less division of tasks and more integration of functions and sections in flexible manufacturing systems (FMS), (Fig. 1)

## **2 FMS - experiencing a rapid growth in number of installations**

No standard definitions exist currently for flexible manufacturing systems and as a result the numbers of such systems in operation in Germany and abroad differ considerably. If a flexible production system is defined as one in which the processing, material and information flow is flexibly automated to the extent that the different workpieces running through the system on the various paths are manufactured without manual intervention, the total number of FMS in the world can be put at about 230 /1/. Figure 2 shows a system in use in Japan and Figure 3 illustrates the most important characteristics of a flexible manufacturing system for gear boxes recently put into commission in South Germany. In view of the overall positive experiences with such systems to date annual growth rates in double figures can be expected both in Germany and abroad. Most medium-sized companies will be confronted sooner or later with FMS and it is likely the number of applications in future will be restricted less by the previous reluctance of users to accept flexible manufacturing systems than by the capacities of the manufacturer of such systems.

## **3 FMS will have to be applied also for production tasks beside machining**

Based on the experience gained in the last few years in the planning and implementation of flexible manufacturing systems for machining of parts efforts are now being intensified to increase the profitability and reaction potential of further production spheres through the gradual



introduction of flexibly automated processing and material flow system.

As a result of very recent development work, sheet metal parts manufacturers in particular have begun to make more extensive use of flexible manufacturing cells and systems, with the different machining processes, such as punching, nibbling and laser or plasma cutting, being integrated in the individual systems. Optimized production processes with short machining times but long retooling and non-productive times also need to be upgraded to reduce these uneconomical sectors by making use, for example, of workpiece and tool changing devices. Such facilities would have a greater rationalization effect than the further optimization of the process by reducing machining times even more. Good results can also be achieved in the transition from cutting in a type-specific complete cutting tool to the slower stamping/nibbling process with its very low workpiece-specific costs. Flexible sheet metalworking machines allowing complete processing of the workpiece on a single machine by suitably combining the various stages, such as stamping/nibbling and laser or plasma cutting, not only help to cut down non-productive times but also lead to a reduction in the amount storage and transport.

The high investment costs required for such systems can only be repaid in a reasonable period if the necessary degree of economic utilization is achieved through appropriate automation devices and corresponding organization. Developments here are tending towards completely automated systems in which the flexible loading, machining and unloading of differing workpieces is CNC controlled and monitored, (Fig. 4).

Figure 5 shows a production system for extremely diverse and small batch plane and two-dimensional sheet metal parts designed in collaboration with the Fraunhofer Institute for Production Engineering and Automation (IPA) in Stuttgart. In this system, apart from a newly developed flexible press system, laser processing stations both for cutting curved sheets and subsequent welding of thin-sided hollow parts were used for the first time /2/.

Developments similar to those used in the metalworking industry are also being initiated in the area of woodworking and plastics processing. Within these sectors, where large batch production has predominated in the past, changed market conditions and the need to respond to varied customer requirements without incurring too great an expense have made the introduction of flexible production structures and newly developed, easily adapted production and handling devices a necessity.

#### 4 Central integration of processing functions

By integrating different production processes on a machine the time taken to complete production is reduced and the number of handling operations minimized. The complete machining of workpieces on machines capable of turning, milling, drilling and even precision machining in one clamping operation is likely to increase in significance. Productivity and flexibility can be improved at the same time through multi-station and multi-tool operation.

The same considerations apply to the use of industrial robots to carry out various different operations and to ensure maximum utilization even with small batches, e.g. when starting up a production process.

The integration of several machining processes by combining the appropriate modules (spindle and clamping units) with fixed basic modules (e.g. columns and guideways) was the main aim of a Japanese project for devising new basic ways and structures for machine tools and assembly devices /3/. Machine tools and assembly cells on the modular principle and the use of lasers in production for machining and chip breaking are just two of the most important areas under consideration. The machining processes can be combined almost at will in two production cells, (Fig. 6), each with three spindles and clamping units together with a driverless transport system for conveying the units for the automatic retooling process. By changing the module it is possible to change over automatically from prismatic to rotationally symmetrical parts.

Initial attempts at basically restructuring traditional types of machines and combining different and hitherto strictly separate machining operations in a single design are now also being made in Europe. Current development work is concentrated primarily on the complete machining of large and heavy workpieces with the aim, amongst other things, of minimizing clamping and retooling times with the aid of a special tool pallet system for turning, drilling, milling and grinding units.

In principle there are two discernible tendencies in machine tool structures:

- in the case of rigid mass production the machining functions are decentralized, i.e. the workpiece comes to the machining function (e.g. transfer line)
- in the case of flexible small batch production the machining functions are centrally integrated, i.e. the machining functions come to the workpiece (e.g. machining centre and lathe cell).

This means in the second instance that maximum technological efficiency in the individual machining functions might not be completely essential when it comes to optimizing the system as a whole.

## **5 Bottlenecks in flexibility will have to be overcome**

If the most recent flexible manufacturing systems are looked at in greater detail a trend is discernible whereby the systems are no longer being bought as complete turnkey installations from a single supplier but are rather being built up gradually by the users on their own responsibility from single manufacturing cells. This procedure is made more difficult, however, by the fact that there are still no standardized material flow interfaces, particularly in the area of machine-oriented workpiece and tool preparation.

In defining uniform and manufacturer-independent standards for interfaces related to peripheral equipment, such as dimensions of pallet or exchange height of pallets, the application of universal means of con-



veyance should be realised independently of the degree of automation of the entire system. Flexibility of elements in direct contact with workpieces, such as handling grippers, clamping devices, or supporting elements to store workpieces in a magazine, cannot be increased at any rate, especially not at a reasonable cost. Therefore support to be put quickly into practice may, to a greater extent, be expected from elements to be rapidly exchanged or adapted and from a further reduction in the variety of workpieces by consequently forming families of parts.

With prismatic workpieces, with their well-known variety of dimensions and shapes, a main hindrance in flexibility and an enormous cost factor, are the clamping devices presently available. Only in a few cases was it so far possible to create a common interface at the workpiece, e. g. by casting an extending finger for clamping, which then, after the machining operation mostly had to be cut off. Adaptive systems are being developed with the ability to recognise the position of a workpiece only roughly positioned on the pallet, and to adjust the machining parameters accordingly. Reducing the manual effort required to load, adjust and clamp different workpieces with automatic clamping devices and handling equipment has also been realized in an experimental stage. However, automated and, at the same time flexible, clamping devices are not to be expected in the near future. These are, however, some developments which are concerned with the automated assembly of clamping devices in using modular fixture elements.

Time- and requirement-oriented provision of tools to the individual production devices continues to be a central problem in the operation of flexible manufacturing systems. In flexible manufacturing cells or systems, tools for drilling and milling of prismatic workpieces are usually buffered in magazines integrated into the machine. Small batch sizes, complex machining tasks and limited tool life call for a large number of different tools near the machine with the result that a considerable amount of capital is bound up in these voluminous magazines. Different solutions have recently been developed in machining centres for the automatic supply of tools at the right time, even during unattended operation, the majority of which aim at provide a complete that of new tools at the machine for each production order.

Transportation of tools from a central tool store and the exchange of tools can be successfully carried out by a mobile industrial robot, (Figure 7). This device, developed by the IPA with a grant from the Ministry of Research and Technology (BMFT) and with the cooperation of a major manufacturer of conveyance and handling devices, consists of an inductively guided vehicle and a pallet which the vehicle can automatically pick up and put down /4/. With the aid of this mobile industrial robot wear and also order-specific tools can be fitted directly in the tool magazine as required.

With the introduction of computer-aided production, recognition systems for automatic identification and classification of workpieces, workpiece carriers or tools is of increased significance, (Fig. 8). With the exception of a few Japanese systems in which workpieces or tools are identified once only at the start of the system and then organized directly by the computer according to the production sequence, the information in the large majority of production systems is organized for reasons of

data security by object with the aid of automatic recognition systems /5/.

Simple mechanical coding systems such as cams are the most commonly used devices for workpiece, pallet or tool recognition as they are the most resistant to damage from chips, dirt or coolants. Their major limitation is the amount of information that can be coded. Because of the aggressive atmosphere in the factory all other coding systems, such as those based on magnetic or optical principles, have to be encapsulated to ensure that they are reliable and legible.

In order to be able to coordinate the increasingly complex workpiece, tool or jig flow, coding systems have to be developed which not only permit data to be stored and read reliable but also allow for modification in accordance with the production sequence.

#### **6 Material flow must be consistent throughout**

The horizontal integration of flexible manufacturing systems, i.e. the organization of the material flow between successive work stations, must be consistent throughout. The implication here is that to achieve an economical overall solution production and assembly cannot be treated as separate entities. Parts which can be manufactured economically but which cannot be transported without interruption to the assembly stations cause additional costs.

Efforts at making available suitable means of transport of the factory-proven European pallet type, (Fig. 9), must be intensified. With the development of modular magazine pallets whose insert modules can even be placed in the magazine frame with the aid of handling appliances the identity of transport, storage, in-feed and assembly units can be maintained without having to abandon existing and proven conveyors and accessories, (Fig. 10). With the aid of a process being developed by the Institute for Production Engineering and Automation (IPA) magazine frames, insert modules and carrier devices for workpieces, clamping elements and handling grippers can be planned, fitted and run through the production and assembly stations with maximum efficiency /6/.

#### **7 FMS will have to be seamlessly integrated into the overall production process**

The increased diversity of products and parts no longer permits economical production of "optimal batches". The capital tied up as a result of overfilled warehouses can account for as much as two-fifths of total assets in many mechanical engineering companies. The isolated optimization of individual targets such as low production costs, short run-through times or reduced stocks often leads to the production operation no longer being conceived or regarded as an overall system. Flexible manufacturing systems which have proved to be an effective aid in consolidating hitherto contradictory targets need to be integrated to a greater extent both horizontal and vertical in the production process. The full significance of this need for horizontal and vertical integration is not fully understood in many companies and for this reason users are



often disappointed that large investments do not always bring about the desired structural change in the entire operation.

In this context, the importance and the continuing difficulties involved with computer-assisted information processing is often underestimated, both from the point of view of the communication between the individual components of a flexible manufacturing system and also the organizational integration of this production area in the overall structure.

Although a number of basic types of machinery and material flow devices can now be discerned in practice, there is still no standardized or transferable control software for organizing and monitoring the different machining and material flow tasks. In the case of small systems with machines from a single supplier various software modules already exist e.g. for DNC operation, tool organization or operating data registration, compiled in accordance with specific customer requirements. But for the majority of systems where a variety of machines, including older and less automated work stations, have to be integrated, time-consuming and cost-intensive development and adaption of the system software must still be carried out and this makes many potential users somewhat reluctant to introduce completely computerized production systems. This represents a considerable development area for university institutes and computer and software houses and high priority in the joint research work in the next few years will have to be given to

- the design of gradually extendable information systems in which independently running partial systems can be combined for user-specific operations and
- the definition of generally valid transferable control modules

with the aim of restricting cost-intensive multiple development and adaptation work to a minimum. In this respect existing steps towards standardization, such as the Manufacturing Automation Protocol (MAP), designed by leading automobile and computer manufacturers in the USA for data transfer, should not be ignored /7/.

Parallel to the development of standardized FMS control software the integration of information flow functions in flexible manufacturing systems also deserves further attention. As with the use of CAD/CAM work stations in design and work preparation, information technology in flexible manufacturing systems should not remain separated and development and production times should be reduced to the economical minimum, (Fig. 11).

Success can be achieved with partial solutions and the idea of proceeding in gradual individual steps - provided they are target-oriented - appears realistic because of the qualifications and risk situation. Future targets must, however, allow for the combination of individual measures and the connection of individual components into an overall CIM (Computer Integrated Manufacture) system. With the aid of this type of hierarchically structured computer and software system, the development of which is still in its infancy throughout the world, it should be possible in the future to coordinate all development, organization and control activities in the various company departments, such as purchasing, work preparation, manufacturing, assembly or marketing, and of

upgrading the overall company operation.

With the use of a logically central data bank all data is registered once only while remaining up-to-date and reliably accessible to all those involved in the production process. This means that both decisions and production sequences can be introduced simultaneously and with common aims in the different technical and economical departments.

In the foreseeable future decision-making processes in computer-integrated manufacturing will remain in the hands of human operators. The computer can, however, help facilitate, assure and speed up this decision-making process and organize and monitor the execution.

## 8 Literature

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Figure 1 :


MANUFACTURING PHILOSOPHY		
traditional	for flexible systems	
DIVISION OF LABOUR		
<ul style="list-style-type: none"> <li>as far as possible</li> <li>- simple work with the lowest wage categorie possible</li> <li>- low implication of work</li> <li>- many interfacing points</li> </ul>	<ul style="list-style-type: none"> <li>as little as possible</li> <li>- qualified work with as qualified staff as possible</li> <li>- high implication of work</li> <li>- few interfacing points</li> </ul>	
EXECUTION OF LABOUR		
<ul style="list-style-type: none"> <li>- batchwise</li> <li>- one step after the other</li> <li>- "bring-obligation" / utilization-oriented</li> </ul>	<ul style="list-style-type: none"> <li>- according to demand</li> <li>- overlapping</li> <li>- "fetching-obligation" / process-oriented</li> </ul>	
TIME REQUIRED FOR EXECUTION		
<ul style="list-style-type: none"> <li>- minimum per operation</li> <li>- maximum output per minute</li> </ul>	<ul style="list-style-type: none"> <li>- minimum per order</li> <li>- maximum utilization per period</li> </ul>	
MATERIAL- AND INFORMATIONFLOW		
<ul style="list-style-type: none"> <li>- separate consideration</li> </ul>	<ul style="list-style-type: none"> <li>- integration</li> </ul>	
		MANUFACTURING- PHILOSOPHY - TRADITIONAL AND FOR FLEXIBLE SYSTEMS  63 800 engl. WA / HHK © IPA

Figure 2 :

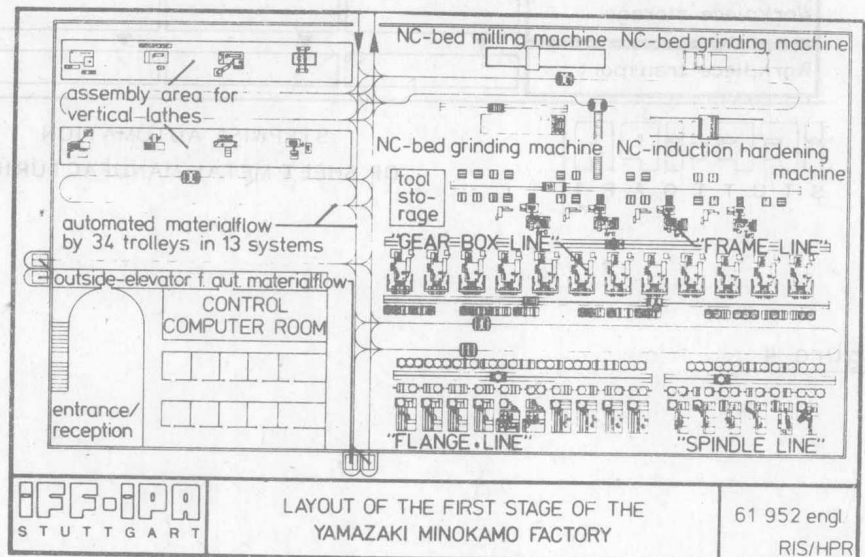


Figure 3 :

