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COMPUTER-INTEGRATED MANUFACTURING

**PERSPECTIVES
FOR INTERNATIONAL ECONOMIC DEVELOPMENT
AND COMPETITIVENESS**



**UNITED NATIONS
ECONOMIC COMMISSION FOR EUROPE**

Geneva



**UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION**

Vienna

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FOREWORD

The microelectronics revolution has profoundly changed the character and the structure of the industrialization process. Industrial automation, flexible manufacturing and computer-integrated manufacturing are some of the areas in which technological developments are strongly influencing industrial competitiveness. The microelectronic-based technologies, by changing the whole international climate in both manufacturing processes and products, are having a significant impact on all countries, irrespective of the level of their development or of whether the technologies are applied there or not. It is equally certain that technology is only one of the issues at stake: matters pertaining to software, organization, management and human resource development are of equal, if not greater, importance.

The impact of the new advances being made in industrial automation are already dramatic and will be even more so in the future. This is true both for the most industrialized countries — such as those that form the membership of the Economic Commission for Europe (ECE) — and for the developing countries, which are the primary focus of the efforts of the United Nations Industrial Development Organization (UNIDO) to promote industrialization.

All these issues have for a long time been of high priority on the agendas of both ECE and UNIDO. It is natural therefore that both organizations devote considerable attention to industrial automation through their respective programmes.

This publication, a joint effort of ECE and UNIDO, results from a realization that the issues covered are of great importance for all countries, both developed and developing. It contains a selection of papers presented at a Seminar on Computer-Integrated Manufacturing organized by ECE in co-operation with the International Institute for Applied Systems Analysis (IIASA). The Seminar, which was attended by a representative of UNIDO, was held at the invitation of the Bulgarian Government in Botevgrad from 25 to 29 September 1989. The papers are introduced by an article that presents an analytical summary of developments taking place, together with some of the more interesting points raised during the Seminar, and attempts to highlight the issues which are considered to have particular relevance for developing countries.

The publication is an expression of the close co-operation which exists between ECE and UNIDO and a demonstration of the potential benefits of increased international co-operation, something in which United Nations organizations and agencies, such as ECE and UNIDO, have a vital role to play.

Gerald Hinteregger
Executive Secretary
Economic Commission for Europe

Domingo L. Siazon
Director-General
United Nations Industrial Development Organization

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Abbreviations

References to dollars (\$) are to United States dollars, unless otherwise stated.

The following abbreviations are used in this publication:

AGV	Automated guided vehicle
AI	Artificial intelligence
AMT	Advanced manufacturing technology
BR	Boundary representation
CAD	Computer-aided design
CAE	Computer-aided engineering
CAL	Computer-aided logistics
CAM	Computer-aided manufacturing
CAP	Computer-aided planning
CAPM	Computer-aided production management
CAPP	Computer-aided process planning
CAQ	Computer-aided quality assurance
CECIMO	European Committee for Co-operation of the Machine Tool Industry
CIM	Computer-integrated manufacturing
CMM	Co-ordinate measuring machine
CMPP	Computer-managed process planning system
CNC	Computerized numerical control
CNCMT	Computerized numerically controlled machine tools
CPU	Central processing unit
CRT	Cathode ray tube
CSG	Constructive solid geometry
DCF	Discounted cash flow
DNC	Direct numerical control
DXF	Data interchange format
EDI	Electronic data interchange
EXAPT	Extended-automatically-programmed tool (programming language for NC machines)
FAS	Flexible assembly systems
FMC	Flexible manufacturing cell
FMS	Flexible manufacturing system
FMU	Flexible manufacturing unit
IGES	International Graphics Exchange Standard
IRR	Internal rate of return
IT	Information technology
JIT	Just in time
LAN	Local area network
MAP	Manufacturing automation protocol
MIS	Management information system
MRP	Material requirement planning
MRP2	Manufacturing resources planning
NC	Numerical control
NIC	Newly industrialized country
OCR	Optical character recognition
OSI	Open-systems interconnection
PC	Personal computer
PLC	Programmable logical controllers
PRIDE	Pinch roll interactive design expert/environment
QA	Quality assurance
QC	Quality control
ROI	Return on investment
SME	Society of Manufacturing Engineers
TOP	Technical office protocol
WIP	Work in progress

INTRODUCTION

I TRENDS AND PERSPECTIVES IN THE DEVELOPMENT AND DIFFUSION OF CIM

by John Bessant, Centre for Business Research, Brighton Polytechnic, Brighton, United Kingdom

1.1 Background

When Henry Ford built his Model T in the 1920s he created an approach to its manufacture which, for its time, was probably the most efficient in the world. Cars could be produced from raw iron ore in just over three days, quality was high and scrap levels low, inventory flowed through the plant with very little tied up in wasteful queues and the whole plant achieved extremely high levels of productivity. So successful was this model for factory organization that it increasingly became applied to other industries and, eventually, services as well. It became, in short, the dominant approach to manufacturing organization up to the 1950s and 1960s, and it still serves as a common blueprint today.

But whilst the market environment in the 1920s was prepared to accept a car made in "any colour you like as long as it's black!" that is no longer true today. Products and services – whether cars, clocks or cookers – are now being sold in competitive markets where demand for variety and customization is high and growing. Nor is the competitive pressure confined to this one dimension of product variety. At the same time, manufacturers are under pressure to offer features such as rapid delivery ("just-in-time" for consumption or for further working), high and consistent quality, advanced design, frequent product innovation and a high level of customer service before, during and after sales. What has happened, especially since the oil crisis of the mid-1970s, is a shift in the nature of the marketplace, away from a pattern characterized by homogeneous mass demand and price competition and towards one which – whilst not neglecting price as a competitive factor – also needs to recognize a whole series of non-price factors. Market fragmentation and increased competition has forced the pace. Manufacturers who wish to compete in global markets must now be capable of meeting the simultaneous challenge of flexibility, quality and productivity.

The extent of this challenge can be seen in the strategic behaviour and intentions of major manufacturing organizations. The following two tables present the results of a regular survey of key manufacturing firms in Europe, the United States and Japan. Table 1 provides an indication of the major issues of current concern amongst manufacturers, and of their future strategic priorities – i.e., what they plan to stress in their future competitive behaviour.¹

From this it can be seen that the challenge to manufacturers is essentially a mixture of internal cost pressures (on inventories, equipment utilization, energy efficiency, labour productivity, etc.) and external demands (for higher quality, better deliveries, etc.) Coupled with this is a recognition that future competitiveness in manufacturing will depend increasingly on non-price factors, as shown in table 2.

This survey refers primarily to manufacturers in the advanced industrialized countries, but the challenge is even stronger in the developing countries. Here there is not only the pressure to achieve some degree of international competitiveness in manufacturing but also to do so in a context of lower levels of skilled human resources, outdated technical equipment and limited managerial expertise. Competition is shifting away from price factors alone and so the advantages offered by cheaper factors of production, such as low labour or materials costs, are likely to become eroded in the future as export markets become more demanding. In addition, the adoption by industrialized country producers of advanced technologies which affect prices, not only by reducing direct costs but also by making major inroads into indirect cost areas, is likely to upset the balance of advantage held by some developing countries pursuing a low-cost export strategy. Table 3 lists some typical developing country problems which need to be overcome if a firm is either to compete in global markets or to defend indigenous markets against imports from more advanced countries.

Table 1

Key concerns of manufacturers in Europe, the United States and Japan

EUROPE	UNITED STATES	JAPAN
High or rising overhead costs	Producing to high quality standards	Producing to high quality standards
Producing to high quality standards	High or rising overhead costs	Yield problems and rejects
Introducing new products on schedule	Introducing new products on schedule	Introducing new products on schedule
High or rising material costs	Poor sales forecasts	Availability of qualified supervisors
Availability of qualified supervisors	Yield problems and rejects	Falling behind in process technology
Inability to deliver on time	Making new process technology work	Ageing workforce
Poor sales forecasts	High or rising material costs	Inability to deliver on time
Making new process technology work	Vendor lead times	Availability of qualified workers
Falling behind in process technology	Indirect labour productivity	High or rising overhead costs
High or rising inventories	High or rising inventories	High or rising inventories

Source: INSEAD, 1986.

Table 2

Competitive priorities into the 1990s

EUROPE/UNITED STATES	JAPAN
Consistent quality	Low prices
High performance products	Rapid design changes
Dependable deliveries	Consistent quality
Fast deliveries	Dependable deliveries
Low prices	Rapid volume changes
Rapid design changes	High performance products
After-sales service	Fast delivery
Rapid volume changes	After-sales service

Source: INSEAD, 1986.

Table 3

Typical problems in developing countries

-
- Underutilization of workers and equipment
 - Inferior quality
 - Unreliable delivery
 - Long lead times
 - High rates of scrap and rework
 - Poor and inadequate maintenance
 - Shortage of raw materials
 - Shortage of skilled workers
 - Lack of adequate supervision
 - Low productivity
-

1.2 The productivity dilemma

Meeting these challenges is not simple. As Abernathy² pointed out in his influential study of the motor vehicle industry, there is a basic trade-off between flexibility and efficiency. Arguably the most efficient model for production is one in which effort is devoted to the manufacture of a single product – a pattern which approaches the characteristics of flow processes. Productivity growth can be achieved through exploiting economies of scale and by concentrating investment in special-purpose capital equipment. By contrast, offering higher product variety implies some form of batch manufacture where there are costs in terms of delays whilst equipment is re-set for different products, increased overhead costs associated with tracking multiple products through the factory, higher inventory costs in raw materials, work-in-progress and finished goods and so on. Productivity here depends upon the ability to produce higher value goods (in terms of design, quality, etc.) in order to sell at higher price markets.

The result is that manufacturers face a trade-off between flexibility (in terms of product variety) and productivity. Market pressures have increasingly forced firms to try and find ways of offering both of these aspects simultaneously – what Abernathy terms “the productivity dilemma.” In the current market environment the challenge is even harder – firms not only have to resolve the flexibility/productivity trade-off but also other trade-offs with quality, service and speed of response and product innovation.³

1.3 Technology to the rescue?

One traditional way of dealing with challenges in manufacturing is to use technology. The latter half of this century has been dominated by spectacular developments which appear to offer ways of meeting the challenge, particularly through the use of information technology in computerized communication and control. These days the term “advanced manufacturing technology” is often synonymous with information technology (IT). Yet even ten years ago the level of application of computers and related technology was relatively low. Although industrial computer systems were available in the 1960s, it was not until the mid-1970s, with the widespread diffusion of microprocessor control, that things really started to happen. But during the past ten years the transformation has been dramatic. Estimates suggest that about 70% of all factories in industrialized countries are using IT in some application; and within larger firms or sectors like the electrical or chemical industry, the figure is closer to 100%. And if we look at the types of application, the extent of this penetration becomes even more marked: almost all manufacturing activities, from initial design and pre-production planning work right through to final delivery, can employ some aspect of IT.⁴

At one level this pervasiveness is easy to understand. IT is usually defined as the convergence of computers and communication technologies, but for our purposes it is more useful if we think of it not in terms of what it is but of what it does. IT makes possible radical improvements in the way in which we store and retrieve information, the way we process it and the way in which we communicate it.

If we look at a typical factory and break down the activities going on within it, then we find that the majority – perhaps 80% – are, at heart, information activities. All the production planning and control, from sales order processing, through purchasing, capacity planning, production scheduling transport and quality functions, right through to final dispatch are essentially information-based processes. Monitoring and control of the various process variables involve combinations of information recording and processing. Design is increasingly an information-based activity. Financial controls of various kinds are critically dependent on information flows and stores.

Thus the potential for using a technology which offers dramatic improvements in the way in which we manage information activities is very significant. What has happened over the past ten years is a gradual maturing of the technology – in terms of costs, applications, configuring to suit industrial environments, etc. – to exploit this potential.

But although IT has undoubtedly been a powerful force for change in manufacturing, it would be wrong to see this as the only factor which has influenced the emergence of advanced manufacturing technology in the form available to us today. Perhaps the most significant trend – which IT has accelerated but which it predates by many years – is the trend towards integration.

1.4 Substitution and integrated innovation

Innovation in manufacturing has been taking place ever since the Stone Age, as new and better ways of doing things have been discovered and developed. But there is a qualitative difference between innovations which are primarily associated with "doing what we've always done but a little better" and those which fundamentally change the nature of the process to which they are applied. In the former case we are really talking about a substitution process – a typical example here would be replacing a machine with one designed to work faster or more accurately. In the latter case, the machine could be radically extended in its capability, for example, by making it able to perform several functions instead of one, or by adding an "intelligent" controller.

The distinction is one of integration. Through a synthesis of different elements, the whole becomes greater than the sum of its parts. As we move from substitution towards more integrated forms, so we bring together more of the previously separate functions in the manufacturing process. At the same time, the benefits which the technology offers increase with higher levels of integration. We move from "more of the same but a little better" – faster, more accurate, etc. – to radically new opportunities which offer significant improvements across a broad front, in quality, in flexibility, in productivity and so on. (In systems theory terms, more integrated systems have "emergent properties," only appearing at the higher levels of integration of sub-systems).

The significance of such integration emerges when there are simultaneous improvements along several

dimensions. Where change is confined to innovations in machinery or methods alone, the benefits are often only at the substitution level. However, when there are changes taking place in production methods, human resource capabilities and machinery and equipment all at the same time, the resulting synergy can contribute radical improvements to overall performance.

We can see this in a number of examples. In the field of manufacturing, for example, the earliest machines built upon the integration of the craftsman's tools with new sources of motive power. Subsequent development enabled a single machine to perform multiple functions, so that although its cost and complexity rose, it replaced several older-generation machines. Nor was this process confined to the physical technology alone. As we have seen, the process of organizing production and the use of labour within a pattern of work organization was also gradually integrated in such a fashion that by the 1920s the Ford assembly lines represented the triumph of integration, linking men and machines into a complex but, even by today's standards, an extremely efficient integrated system. This also involved the integration of supply chains and distribution.

Other developments in machinery in more recent years have included the integration of "intelligence," gradually replacing the judgement of individual craftsmen by the incorporation of some form of machine controller – originally numerical control (NC), then computer numerical control (CNC) followed by arrangements of CNC equipment in cells supervised by other computers (direct numerical control DNC), through to today's state of the art, the flexible manufacturing system (FMS). In an FMS all the functions of transport and manipulation, tool management, loading, unloading, and overall scheduling and planning are managed by a DNC-type network of linked computer controls. In the future we can expect to see this process go even further, with the increasing use of artificial intelligence. Thus over a period of 150 years or so we have moved via this integrating process from a single machine tool to a complete manufacturing system. In the process, the range of benefits emerging from the innovation have moved from better and faster machining to much more powerful and strategic advantages such as lead time reduction, quality improvement, flexibility improvement and inventory saving.

The same trend can be observed in other areas of manufacturing. For example, in the field of design, the various tasks associated with this complex process have gradually become integrated into computer-aided design systems. In this process, the traditional drawing office with its rows of draughtsmen crouched over drawing boards has been replaced in many cases by computer-aided design in which the designers work with computer terminals. This changes a great deal of their work, although superficially they are still accomplishing the same task, except with an electronic pencil.

The first change is that the activities of design and draughting have converged. Whereas before, much of the design department's work consisted of a laborious drawing of ideas and redrawing to accommodate changes and improvements, this can all now be done using the computer system. More important, the drawing on which a team of designers are working at any moment is automatically updated with the results of changes made by any other designer. This means that for the first time all designers are working on the same project, and in the design of complex assemblies like motor cars, such a feature can mean significant savings.

But even allowing for the very powerful contribution of computer-aided design to the draughting and design process, its real significance emerges as IT facilitates its integration with the manufacturing process itself. Since computer-aided design (CAD) systems make use of information coded in electronic form, it follows that other systems, such as those for computer-aided manufacturing which also use such information, can be linked via some form of network. This is the basis of CAD/CAM - computer-aided design and manufacture - in which not only can the product be designed on a computer screen but, when the design is finally refined, the necessary instructions can be generated and sent to the machine tools and other devices which will actually manufacture it.

The advantages of this kind of integration are enormous. They extend beyond the generation of designs and the relevant information necessary for controlling the manufacturing process to those for

other activities, for example, for managing the various co-ordination and control activities such as material requirements planning, capacity planning and quality control. Benefits arising from this include significantly reduced lead times, improved quality, better machine utilization and much improved customer service.

One other feature worthy of comment here is that, whereas Henry Ford was able to achieve very high levels of productivity and efficiency in his plant through integrating different physical elements into the assembly line, this led to rigidity and centralization, which ultimately acted against the company's competitiveness. By contrast, today's systems can offer - as a consequence of network technology - the possibilities of "flexible integration," in which systems can be tightly coupled and highly centralized and, at the same time, highly decentralized and autonomous.

1.5 Computer-integrated manufacturing and beyond

Until now, such integration has usually taken place within particular functional areas of manufacturing, as illustrated in figures 1, 2 and 3. So the major changes in design have largely remained in the design and drawing area. Improvements in machining systems have mostly been confined to the factory floor and to specific areas within that.

However, recent developments have begun to blur the lines between functions - as in CAD/CAM systems, for example (figure 4). They make use of the feature that IT-based systems use a common electronic language and can thus be configured to communicate with each other via some form of network.

This is the basis of computer-integrated manufacturing (CIM), which can be defined as: "the integration of computer-based monitoring and control of all aspects of the manufacturing process, drawing on a common database and communicating via some form of computer network." Figure 5 shows this development from integration within functional areas towards inter-area integration and finally CIM.

Figure 1

Convergence in design**Integration in design:**

- Computer-aided draughting
- Data base management of design information
- Computer-aided design
- Computer-aided design and manufacturing (CAD/CAM)
- Links to planning, purchasing etc.

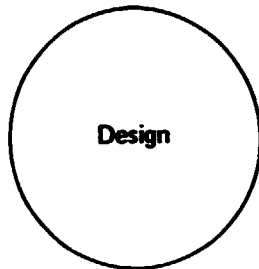


Figure 3

Convergence in co-ordination activities**Integration in co-ordination:**

- Material requirements
- Material requirement planning
- MRP2 (manufacturing resource planning)
- Integrated manufacturing and business systems

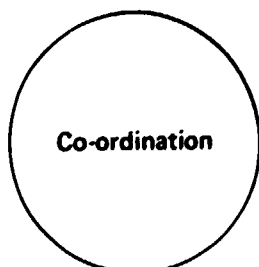


Figure 2

Convergence in the production sphere**Integration in production:**

- Monitoring and control
- Integrated cells
- Robotics
- Flexible manufacturing systems
- Automated testing
- CAD/CAM

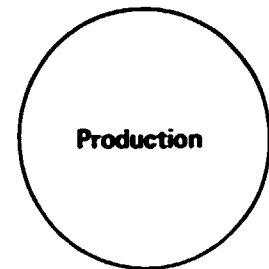
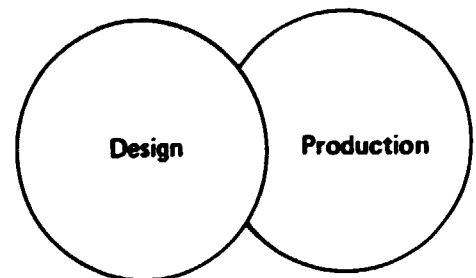
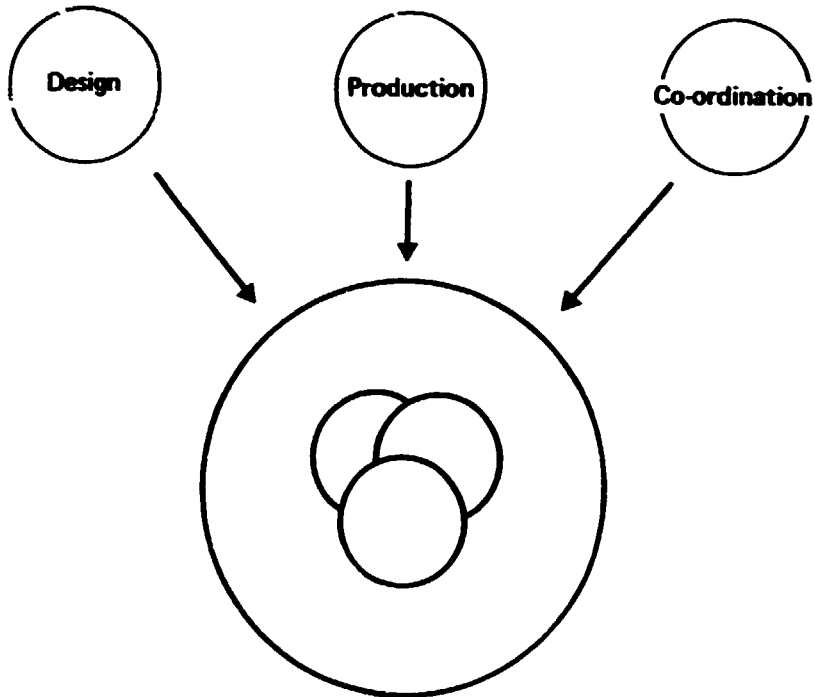


Figure 4

Convergence towards CIM - the case of CAD/CAM

Integration begins to blur the lines between spheres of activity, for example, computer-aided design and manufacturing (CAD/CAM) involves convergence at several levels.

Figure 5
Convergence to CIM



Source : Based on Kaplinsky, 1984.

Computer-integrated manufacturing

Figure 6
Computer integration beyond the firm

Computer-integrated manufacturing does not stop
at the boundaries of the firm . . .

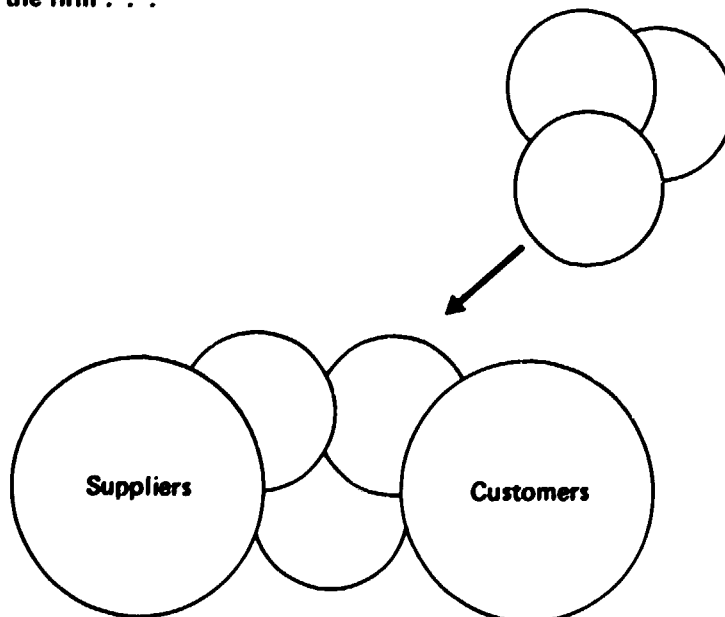
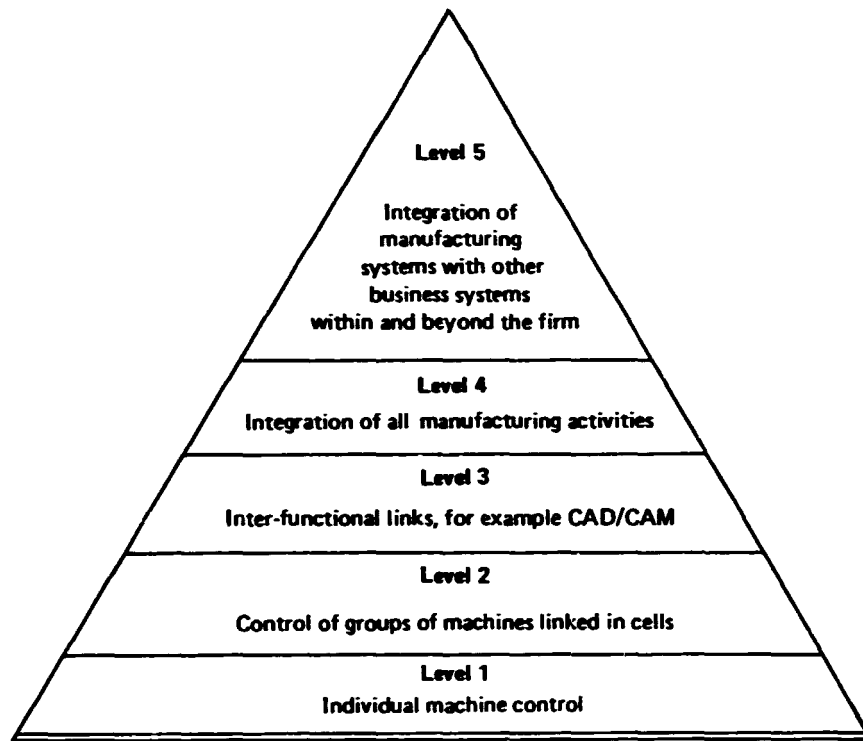


Figure 7

Basic CIM hierarchy



Of course, such integration does not stop at the boundaries of the firm (see figure 6). Integration via electronic means can also extend backwards along the supply chain (with, for example, shared design processes or electronic components ordering linked to inventory management computers) or forwards into the distribution chain, using what is termed "electronic data interchange" (EDI) to speed the flow of products to outlets whilst also minimizing the inventory held within the chain.

Computer-integrated manufacturing essentially brings together two key aspects of manufacturing activity – the materials processing and the information processing. Automation has already had a major impact on many of the physical transformation processes in use, to the extent that direct labour costs in engineering, for example, are often less than 10% of total costs. Emphasis has shifted to indirect activities, many of which involve information processing or communication, and the application of IT in these areas is beginning to contribute significant improvements in performance. CIM offers radical improvements in overall manufacturing effectiveness since it merges these two powerful forces for change.

One of the most common models for CIM is some form of hierarchy or pyramid, as indicated in figure 7. Here the basic level operations – machine controllers, data collectors, etc. – operate autonomously but also communicate information to the next level, covering the overall monitoring and control of a cell. This would, for example, be the case with a simple flexible manufacturing cell. Further up, a plant controller would handle the activities of several cells, co-ordinating their use of resources and monitoring their overall performance. Level four would involve the integration of other key functional areas, for example, design and marketing, and would represent a shared information system of the kind represented by Manufacturing Resources Planning (MRP2). An important element is the Automated Guided Vehicle (AGV) in the integration of production processes at shop-floor level. Level five would be an overall business systems integration, in which the financial and sales information would be linked into the manufacturing system and level six would be the overall board-level strategic view, which includes long- and short-term perspectives, etc.

The common characteristics of this kind of architecture are that they involve networks and that

information can be shared throughout the system. Changes anywhere in the system will update the rest of the information in the system. So, in one sense, the entire operation can be seen to behave as if it were a single enormously complex machine. But this is not, as some critics have suggested, simply a centralizing and concentrating process. The key property of the networks which form the "nervous system" for CIM is the ability to be simultaneously highly centralized and highly decentralized. Thus the economies of shared resources and information can be added to those of local autonomy and flexibility in uncertain environments.

1.6 Benefits of computer-integrated manufacturing

Such developments towards CIM do not just offer considerable improvements in traditional ways of making things. They also open up completely new and often highly integrated options. And the contribution which such changes can make to dealing with the problems of the market environment as we move to the 1990s and beyond are equally significant. Pressures on firms to be more flexible, to offer high quality, better customer service and improved delivery performance and to emphasize design and other non-price factors all pose major challenges to manufacturers to add to the "traditional" burden of ensuring effective use of inputs of energy, materials, labour and capital.

CIM differs from other technologies in its impact on indirect cost areas as well as direct costs. It contributes to better co-ordination, it tightens the linkages between previously separate elements in a production chain, it brings powerful planning and monitoring tools to bear upon the problems of production control, and it reduces the amount of paperwork required to maintain even a simple manufacturing system. Thus, any of the traditional areas of overhead cost – which can often account for 40% or more of total product costs – can be reduced, adding further to the competitive benefits offered by CIM. CIM in this context is seen as a

major and valuable competitive weapon. Table 4 compares the benefits offered by CIM with the key challenges confronting manufacturers as they move into the 1990s.

1.7 Supply-side growth

The third trend which is of importance in considering the development of advanced manufacturing technology concerns the supply side. As a consequence of the growing pressures on manufacturers to find solutions to the strategic problems of the 1980s and 1990s and the emergence of powerful heartland technologies with widespread potential, we have seen an explosion of growth in the industry concerned with supplying manufacturing innovation. The IT industry as a whole is expected to be worth some \$600 billion by the 1990s and to have overtaken oil as the world's biggest industry. Although this figure includes the major contribution from the telecommunication field, the importance of that technology in providing the networks for CIM should not be discounted. Estimates for 1985 suggest that the global expenditure on industrial automation was of the order of \$38 billion, rising to around \$50 billion in 1989 and with predictions for 1992 of about \$90 billion.

Within the automation industry, the sectors concerned with supplying advanced manufacturing technology (AMT) have already demonstrated very rapid growth – typical annual sales growth has been in excess of 20% for many products or systems. Such rapid supply-side growth has both positive and negative consequences for the potential user. On the plus side it means that there is a proliferation of choice. For any item of AMT which a firm might be considering buying there is a wide and growing range of options from which to choose. This choice spreads across several dimensions, to suit firm specific elements, such as cost, firm size, industrial sector, level of skill and previous experience. The effect of massive supply-side growth has been to create a buyer's market, in which customers can demand high levels of service and support and customization to meet their particular needs.

Table 4

Computer-integrated manufacturing: a solution for the manufacturing problems of the 1990s

Main problem issues as seen by senior manufacturing executives in Europe	Potential contributions offered by CIM
Producing to high quality standards	Improvements in overall quality via automated inspection and testing, better production information and more accurate control of processes
High and rising overhead costs	Improvements in production information and shorter lead times, smoother flow and less need for supervision and progress chasing
High and rising material costs	Reduced inventories of raw materials, work-in-progress and finished goods
Introducing new products on schedule	CAD/CAM shortens design lead time Tighter control and flexible manufacturing smooths flow through plant and cuts door-to-door time
Poor sales forecasts	More responsive system can react quicker to information fluctuations. Longer-term, integrated systems improve forecasting
Inability to deliver on time	Smoother and more predictable flow through design and manufacturing stages makes for more accurate delivery performance
Long production lead times	Flexible manufacturing techniques reduce set-up times and other interruptions so that products flow smoothly and faster through plant

But on the negative side, the expansion of the supply side into a large and highly competitive industry means that there is considerable pressure to sell. For inexperienced users there is the very real danger of being subjected to high-pressure sales techniques which are not intended to solve a particular manufacturing problem but rather to shift a particular seller's set of boxes. Thus there is an important need for user firms to develop skills in the choice of technology to meet their particular needs.

The problem is exacerbated as we move along the continuum from substitution innovation to integration. As we begin to talk of major investments in manufacturing systems, covering a number of functional areas rather than single items of equipment, so we begin to approach the limits of experience on both the supplier and the user side. For example, an

engineering firm might understand fairly well the problems involved in buying a new machine tool, and the supplier of those tools will attempt to address these concerns. But when the question is one of a flexible manufacturing system, which brings together machine tools, computers, robots, automatic transport systems and software, the problem becomes much bigger than any most firms have experienced before. The limits of their learning curve will have been reached and their ability to manage the process of selection and implementation will be limited.

On the supply side the same problem is also emerging, as the move to selling systems rather than individual items of equipment comes to the fore. The supplier of machine tools is suddenly challenged to become a much more broadly based supplier, requiring competence in computer hardware and software,

robotics and automated transport technology, factory automation networks and so on. In the short term it is likely that the ability to provide a solution to the user firms' problems may also be limited by the supplier's own inexperience.

The effect of this is to introduce considerable uncertainty into the selection stage of the innovation process. A number of strategies have emerged to cope with this problem, ranging from delaying investment until such time as the market matures to the extensive use of external consultants and advisors. (In this connection it is interesting to note the rapid expansion of the manufacturing technology and management consultancy industry and the particular interest in "systems integration contracting." That is, the provision of services analogous to those of a "managing agent" in a major building project, taking responsibility for putting different contributions together and for bringing the project in on time and within budget.)⁵

On the supply side there is the recognition of the limits to the ability of any one firm – even amongst the largest vendors – to supply complete systems expertise and products, and this has again led to several coping strategies. There have been a variety of mergers, acquisitions and "strategic" alliances between firms, all designed to try and broaden the range of products, competence and experience which can be offered.

Perhaps the most interesting trend has been the emergence of early users of advanced manufacturing technology (especially in its more integrated forms) as suppliers of systems and expertise. Their argument here is that they had to undergo considerable learning and development in order to solve their own problems, often including coping with an immature and disorganized supply side which was unable to meet their particular needs. Consequently, they have now accumulated a reservoir of knowledge and experience on the basis of "learning by doing," which has considerable commercial value.

So the overall picture of the supply side is one of enormous potential and choice, but also of continuing development and maturation. The effect of this is to make the selection environment highly complex and uncertain, and to emphasize the importance of skills and competence in this area as a key feature in the successful implementation of AMT. Two questions of particular concern for many smaller firms and those operating in developing countries are how to identify the right time for entry into CIM, and the right level.

Both these can only be answered successfully if the decisions are taken within a clear strategic framework.

1.8 Experience with CIM

At first sight CIM appears to represent a perfect marriage between technological potential and the manufacturing challenges of the 1990s. Experience in a variety of countries and industrial sectors confirms the powerful advantages which can be gained and highlights improvements in overall business effectiveness measures rather than simply in improved efficiency in areas within the factory. For example, Fittle cites a United States Government study of five cases of computer-aided design and manufacturing in which the average inventory savings were 35%. In another case he reports a United States pump manufacturer investing \$9 million and obtaining annual savings of \$10 million plus a one-off saving of inventory of \$11 million; in addition throughput time was reduced from 25 to 2 days.⁶

In studies of flexible manufacturing systems in the United Kingdom and Sweden, we found average figures of inventory savings of 70% and of lead time reduction of 70%, and similar figures have been reported in other studies from various European countries and from Japan.⁷

But there is another side to the coin. Evidence is accumulating to suggest that much of the investment in advanced CIM components, such as flexible manufacturing systems, integrated management software for manufacturing resources planning or computer-aided design and manufacturing, is not being used to anything like its full potential. In a few extreme cases the considerable investment has failed completely, but in most cases it is more a matter of underutilization of the potential. For example:

- In 1989 the United Kingdom was reported to be investing in CIM at a rate of nearly £2 billion/year, equivalent to 20% of all capital expenditure in manufacturing. But up to a third of that money is being wasted – integration has occurred only on a technical level and not on an overall business level. In particular, "benefits on the whole have been disappointing with an achievement of 70% of planned gains... CIM has not resolved the problems of quality and performance to schedules as anticipated.... MRP has only managed to tidy up and enforce disciplines without achieving the two primary goals it claims to resolve i.e. inventory reduction and adherence to deadlines."⁸

- In another United Kingdom study of users of various types of advanced manufacturing technology, managers were asked to rate their investments in terms of their (subjective) views of the return to the firm. Their responses suggest that nearly half the users of computer-aided design were dissatisfied whilst 70% of users of FMS and nearly 80% of robot users felt their investments had given them "zero to low payoff."⁹
- In a study of 33 firms using computer-aided production management (CAPM) systems, nearly a third were considered by users to have been failures. The study concluded that "...even advanced users ...are not getting the full benefits from their systems."¹⁰
- In comparing the operation of flexible manufacturing systems in the United States and Japan, Jaikumar found that, for similar systems, Japanese users were able to obtain higher productivity and flexibility from their systems.¹¹ Table 5 highlights the main results of this study.
- In a research programme on advanced manufacturing technology users carried out on behalf of the United Kingdom National Economic Development Office, Burnes reports that "..... of the 21 systems observed, 12 were operating satisfactorily but the other 9 were performing considerably below expectations. Indeed, the performance of one system was so bad that the company eventually scrapped it altogether..... Even in the 12 instances where satisfactory performance was achieved, in four cases there were major problems and long delays had to be experienced in bringing the systems up to expectations."¹²
- Another United Kingdom study commented that "..... only about 25% of CAD/CAM installations in the UK are considered a success. From the logistics perspective, the CIM track record is even more suspect; if we consider logistics is all about having the right resources at the right place and time then a substantial number of MRP2 installations can be considered failures."¹³
- Recent evidence from the USSR concerning flexible automation shows that "no less than a third of the 50,000 industrial robots produced between 1981 and 1985 had not performed even one hour's work. A sample inspection made by the People's Control Committee of the USSR in 1985 showed that the annual return on introducing 600 robots, at a cost of more than 10 million roubles, was a mere 18,000 roubles."¹⁴

Table 5

Comparison of United States and Japanese FMS installations

FACTOR	UNITED STATES	JAPAN
Number of different parts produced/system	10	93
Number of parts produced/day	88	120
Number of new parts introduced year	1	22
Utilization rate (based on 2 shifts)	52%	84%
Average metal-cutting time (hours day)	8.3	20.2

Source: Jaikumar, 1986.

So it is clear that unlocking the full potential gains offered by expensive CIM investment involves more than simply making the decision (and finding the capital) to adopt the technology. There is little doubt that the use of CIM can be very profitable, but this will only be the case if its introduction is linked to clear strategic objectives and its implementation is managed carefully. Potential users of the technology should look at, and learn from, failures like those described above as well as successes.

Examination of cases in a variety of studies confirms the view that there are two key features associated with successful implementation of CIM. The first is that the investment is made within the context of a clear strategic framework. Rather than selecting and investing in CIM because it is a fashionable technology, successful firms have a clear understanding of their business, knowing where they want to be in the marketplace and how they plan to compete and the implications this has for manufacturing. They also know their present strengths and weaknesses within their manufacturing operations (in terms of equipment, facilities, experience and skills) and can

plan a step-by-step strategy which builds up to highly integrated automation in a series of stages rather than a quantum leap.

The second key point is that successful firms recognize that they need to make significant and far-reaching changes to the way production is organized and managed. Using a "revolutionary" technology such as CIM requires a similarly radical degree of organizational change along a number of dimensions, including the skills profile, the functional and hierarchical structure, the philosophy of management and control and the underlying culture of the organization. The argument has been advanced that we are now in an era which is moving away from the Fordist pattern in terms of mass markets and dedicated technologies based on scale economies and are entering a new post-Fordist era characterized by emphasis on flexibility, variety and economies of scope. If this is the case, then a central feature of the change will be the emergence of new models for organization and management.

1.9 CIM and new techniques in production management

One of the problems in looking at technology is that we often assume a narrow definition of the word, treating it as synonymous with hardware or computer systems. But the dictionary definition is much broader, referring to "the useful arts of manufacturing" and essentially describing a total system including both tools and the way in which they are used. This alternative view is important because it reminds us that considerable improvement can often be obtained with minimal capital investment by changing existing practices in production organization and management.

In this connection it is important to highlight the experience in the use of new approaches such as "just-in-time" and "total quality management," both of which have been credited with making possible the extremely powerful performance of Japan as a manufacturing nation during the past thirty years.

These concepts are often misunderstood outside Japan, being seen as narrowly applicable techniques to deal with specific problems rather than as much broader philosophies which provide a framework within which a variety of tools and techniques are deployed. For example, the basis of just-in-time is that most factories give rise to a great deal of waste - in materials, in human and machine effort, in monitoring and control systems, in movement and in time. The approach begins by setting the ideal goal of producing or doing things "just in time" for them to

be used by the next element in the chain throughout the manufacturing process. Emphasis is then placed on problem-solving on a broad front to try and achieve this ideal or at least to get as close to it as possible. This may involve changing the physical layout of production, changing the way in which work is organized, re-equipping machines, reducing set-up times, changing the inventory management system, etc. The focus of such techniques is thus less on improving direct efficiency of equipment than on ensuring smooth flow throughout the factory. This shift in emphasis assumes considerable economic significance when we consider that, in engineering, for example, a product may spend less than 5% of its time in the factory actually being machined or operated upon, with the remainder taken up in waiting or transportation time.

Total quality management involves a similar and interrelated approach which sees quality as something much more than just a narrow attribute of a product or service. It also stresses a company-wide involvement in the problem of quality improvement and involves a range of tools and techniques aimed at mobilizing problem-solving efforts towards the goal of "zero defects."

Central to both of these philosophies are two elements. The first is the involvement of every employee in the process of problem-solving, and the mobilization of their commitment towards a common goal. The second is the idea of continuous improvement, which ensures that progress is maintained over the long term.

It is often argued that these approaches are effective but can only work in Japan. Whilst it is true that they have been successfully developed and implemented in Japan during the past thirty years, there is nothing particularly Japanese about them and there is growing evidence of their application in a wide variety of countries, industrial sectors and firm sizes. Further, most of the underlying ideas derived from experience in Western factories - for example, many of the principles of just-in-time come from classical work study developed in the 1920s in the West, whilst total quality management was also developed in wartime factories in the United States and Europe.

The potential of these techniques for improving manufacturing performance is considerable and there is growing case-study evidence to support it. Importantly, these benefits are again not confined to efficiency improvements in a narrow area but have an impact on the overall competitive effectiveness of the firm. For example, many studies report savings in

excess of 70% on lead times, inventory levels, space and quality problems. In addition, programmes of this kind offer other, less tangible benefits such as improved employee motivation and contribution. For example, at Toyota, the average number of suggestions offered by employees for improvements in products and processes approaches 2 million per year, of which the vast majority are adopted.

Perhaps the most significant point about such changes is that they represent a valuable entry point for CIM for two reasons. First, they can generate significant savings for a relatively low investment. And second, because the nature and direction of change – new layouts, new patterns of work organization, new organization structures, etc. – are precisely those which are needed to support more advanced and capital intensive applications of CIM. There is thus no conflict between CIM or changes in production methods but rather a complementarity. So the emerging model should be seen not simply as the extension of technical integration but rather as the convergence of two streams – new IT based equipment and systems and new approaches like just-in-time and total quality management. Rather than simply computer-integrated manufacturing, we should perhaps be talking about total integrated manufacturing.

1.10 Is CIM relevant to developing countries?

Until now we have seen the enormous potential for CIM as a mechanism for improving manufacturing performance along a number of competitiveness dimensions. We have also seen the significant barriers which militate against its effective implementation, including high capital costs, software development problems, lack of standardization, immaturity of the supply side and a lack of key skills. All this would appear to argue strongly that CIM is an inappropriate technological choice for developing countries.

There are at least two reasons for questioning this viewpoint. First, there is the issue of the changing nature of the competitive environment, with its increasing emphasis on non-price factors such as design, quality and delivery responsiveness, in addition to continuing emphasis on price competitiveness. This means that increasingly export markets will only be accessible to those firms able to develop and maintain a competitive edge based on this broad range of factors, rather than narrowly on price advantages. Strategies which have in the past relied upon advantageous factor endowments such as low labour or materials costs, may be less viable in the future.

Pressure is also likely to be exerted through transnational corporations as key actors to extend the basis of competitiveness into non-price areas. For the same reason, domestic markets are likely to be subjected to increasing penetration from external competitors offering not only price but also non-price advantages, which may have the effect of eroding indigenous industrial capability if it is not able to adapt to the new rules of the competitive game. Because CIM offers advantages both in price (as a result of cost reductions due to direct automation and especially through automation of indirect, overhead activities) and in non-price areas (such as design and quality), it is likely to prove an extremely potent weapon in the competitiveness battles of the 1990s and beyond. For this reason, a passive strategy based on leaving CIM to a handful of advanced industrialized nations seems very risky.

The second important reason for questioning the apparent irrelevance of CIM to developing countries lies in the nature of the technology itself. CIM is not, as this article has tried to demonstrate, simply one more neatly packaged box of technology to be bought off-the-shelf by those best able to afford it. It is, instead, an approach, a strategic framework involving a variety of components of hardware, software and organization. Its successful implementation requires considerable organizational learning and development, including a significant proportion of what might be called "un-learning." It cannot (if we are to judge from early experiences) be implemented in a "big bang" fashion but instead requires a systematic, step-by-step development, towards a long-term strategic goal. This process of incremental innovation towards full CIM offers considerable opportunity for organizational learning and development.

CIM is fundamentally a strategy, a philosophy for improvement rather than a piece of equipment, and it provides a coherent framework for the development of any manufacturing enterprise. The first step – organizational change, product and process simplification and redesign – essentially involves challenging the existing patterns and models of manufacturing organization and management. Without such a starting point, even the most expensive investments in advanced information technology run the risk of simply making things worse by "computerizing chaos."

The prescription in outline is simple. It involves taking a strategic view of the total business and deciding what is to be made for which markets and how products are going to compete in those markets. From this, a strategy for manufacturing can be

developed which asks how these competitive criteria can best be supported, and from this develops a step-by-step programme of technological and organizational change towards this goal. Much benefit can emerge from the early stages of this process where the existing pattern of manufacturing is compared with what ought to be there to support the strategy; it is essentially a rethinking and a challenging process.

The benefits of taking this first step can often be significant. For example, in one plant, part of the United Kingdom-owned Lucas group producing fuel injection equipment for diesel engines, 1984 saw a major crisis of competitiveness, with a falling market share, poor quality and reliability, declining customer relations, etc. As a result of analysis of this, a major strategic change programme was embarked upon which involved extensive organizational development but relatively little investment – only £1.5 million over four years.

Essentially, this programme involved the reorganization of the plant into separate manufacturing cells. Production was simplified by creating three mini-factories, each focused on a small coherent family of products. At the same time, the management hierarchy was reduced from seven layers to three. On the employee side, jobs were transformed from those requiring "human robots" to those needing problem solvers with flexibility within and across cells. The necessary skills development was backed up by training and by placing stress on common ownership of manufacturing problems.

The culture moved from a traditional crisis management factory, oriented to output, to one which stressed continuous improvement. The results include massive cuts in lead times (200%), improvements in delivery reliability, increased inventory turnover (from 22 to 34 times and rising), higher quality (up by 12-15%), savings in space through better layout and a productivity improvement of about 50%. Perhaps the most significant achievement here has been that almost all this benefit came without extensive capital investment but with systematic challenge to the existing organization and management of production.¹⁵

Cartaya and Medina¹⁶ report on another case in Venezuela where a systematic challenge to existing ways of operating a shoe factory helped bring about radical improvements in productivity, quality and flexibility. Posthuma reports on work in the Brazilian automobile industry which indicates that significant improvements could be obtained even at the early stages of implementing a total quality programme,

through the use of simple statistical process control techniques.¹⁷

Recent reports from the International Motor Vehicle Programme comparing performance of car assembly plants along key dimensions, such as productivity, quality, flexibility etc., conclude that a new model for manufacturing is emerging, which they term "lean manufacturing," not least because it seems to involve production through less – less labour, less material, less quality problems, less time taken in design and manufacture, etc. The key to successful "lean manufacturing" plants (of which one of the best performers is in Mexico) lies in a new approach to production organization and management, moving the car industry beyond the models originally developed by Ford and Sloan in the early days of the industry.¹⁸

In each of these cases the process of rethinking and challenging has highlighted areas in which change is needed and considerable benefits have flowed from relatively small and simple first steps.

Of course, long-term competitiveness will depend on more than organizational changes and product/process redesign. But without this initial stage, no organization can expect to make full and effective use of the opportunities opened up by technologies under the CIM umbrella. It is a total system change to a new pattern of best practice. (Significantly, in the International Motor Vehicle Programme study mentioned earlier, the contribution of advanced automation technology to improved performance was relatively small; the key changes came through adoption of alternative organizational models and practices associated with "lean manufacturing.") It is the adoption of continuous improvement values, the involvement and participation of the workforce, the changed customer orientation, the responsive organizational structure plus advanced manufacturing technology which holds the promise for the future in manufacturing.

There is no short cut to successful CIM, but rather a step-by-step learning strategy, and this applies to industrialized and developing countries alike.

1.11 Implementing CIM

With this broader definition of CIM which includes changes in organization and methods as well as production equipment, we can now turn to the question of implementation. Central to this issue is the need for a clear strategic framework which sets out the long-term goals of the company and within which step-by-step progress can be made. Implementing

new technology is not a manufacturing version of a shopping expedition in which the main problems are which shops to go to, what products to buy and how to pay for them. Rather, it is a process with a long timescale and many dimensions.

We need to see manufacturing innovation as a long-term problem-solving process and to explore approaches to its effective management. Much of the running in effective manufacturing management in recent years has been made in Japan and it is not coincidental that the two themes – creative problem-solving and continuous improvement – are dominant features of their approach.

Problem solving is usually represented as a sequential process which begins with recognition, an awareness that a problem exists. This needs to be refined and defined/redefined to clarify and focus on the core problem. Without careful attention to the problem definition stage, it is easy to engage in solving the wrong problem, or in trying to deal with a symptom rather than a cause. Experience shows that this iterative process of arriving at the problem definition is best carried out with a variety of information and experience inputs.

In the case of new manufacturing technology, there is no shortage of problems to which the technology could be addressed. But without a careful, systematic and strategic analysis/audit of the particular issues involved, it is quite likely that the wrong problem will be treated. For example, a typical justification for installing a computer-aided production management system is to try and reduce inventories and improve delivery performance. However, the root cause of these problems is often related not to the need for a faster and more powerful information system to keep track of things more efficiently but to the presence of an overly complex system already in place, trying to keep control of a manufacturing process which has, over time, evolved into something which no one fully understands. The real need here is not for more technology – that would only have the effect of "computerizing chaos" – but rather for a simplification of the existing arrangement. Once this has been done, the next stage might require investment in a computer system, but it might also be amenable to other solutions.

In defining the problem, it is also important to take into account the different pieces of information which might help in arriving at a complete and useful statement of the problem to be solved. This may well involve various people with their own particular mix of perspective, experience and knowledge. For

example, in developing a technology strategy, it may be very useful to bring in operators and supervisors from the shop floor who have a day-to-day exposure to the particular key issues which prevent the firm from achieving its competitiveness goals of flexibility, responsiveness, etc.

Once the problem has been defined, the next stage is to explore the range of potential solutions to this problem. This is again an activity which benefits from having a number of different perspectives and, once again, it is an iterative process. Exploring the possible solutions may lead to further redefinition of the problem. Evidence also suggests strongly that the quality of the final solution is improved by spending time here generating a range of alternative options rather than choosing the first and most obvious answer. It may not be – and often is not – the best.

This highlights a typical behaviour pattern in adopting new technology. Because of the widespread availability of powerful technology and the perception of major problems facing the firm, the tendency is to look for "plug-in" solutions – the quick technological "fix." So, for example, firms requiring greater flexibility will often decide to try and buy a flexible manufacturing system which, to judge from the label, represents the obvious solution. In doing so, they jump straight from a definition of the problem to a solution without adequately exploring alternatives. By contrast, many firms have now discovered that organizational change routes – such as the use of just-in-time systems – can also solve their problems of flexibility. Rather than buying flexibility, they have explored ways of becoming flexible systems themselves. Such alternatives are often cheaper and more compatible with the organization but finding them requires considerably more in the way of exploration of the options available to solve the problem.

Once a range of potential solutions have been explored, the next step is to select a particular option. As we have already seen, making such choices is often a highly uncertain process, particularly in a selection environment where there is limited information or experience and where there is strong sales pressure from suppliers. Here again the contribution of a range of experience and information is of value, particularly in ensuring that the selected solution is one which will be appropriate to the broader context in which it will have to work, as well as in solving the problem to which it specifically relates.

Finally comes the whole problem of actually implementing that solution, of introducing it into the

organization to deal with the problem originally identified at the start of the process. It is here that one important payoff from involving a wide range of staff in the earlier stages emerges: the more they have participated in the problem-solving process, the more they will feel a sense of "ownership" of the solution and a commitment to making it work.

Perhaps the key lesson for the management of technology here is to treat innovation as a systematic problem solving process and to ensure that sufficient attention is paid to each stage and to avoid jumps and short-cuts in a misguided attempt to speed up the process. In the latter case, the result is likely to be a lower quality solution.

1.12 The need for a strategic approach

Moving to CIM is, above all, a strategic activity. Entering this technological field is not simply a matter of a short-term investment in one or two discrete items of equipment but rather a long-term philosophy involving technological and organizational components which need to be carefully linked to provide support for the overall business. Successful CIM implementation is a matter of step-by-step progression within a long-term framework, with each stage being evaluated and cost-justified, and with post-investment auditing to ensure that the strategic objectives have been met.

Too often, CIM components like FMS are installed with little idea of the strategic objectives or of criteria to assess their contribution to meeting these. Where criteria exist, they are often defined in a narrow technical or financial sense rather than taking in the wider context of the organization's business environment and needs. For example, the success of an FMS might be judged against its cost, its payback and its contribution to cost reduction and output maximization within a small part of production, rather than by increases made to overall organizational responsiveness and agility in a competitive marketplace.

To be effective, a CIM strategy must begin with a thorough analysis of the business needs and a clear plan which identifies the basis on which competitiveness will rest in the long and short term. From this, the key order-winning criteria – flexibility, agility, quality etc. – can be derived.¹⁹

The next stage requires a review of existing manufacturing operations, in terms of their local strengths and weaknesses and the way in which they fit into this broad strategic framework. Simultaneous

with this is the requirement for a thorough exploration of opportunities opened up not only by new manufacturing technologies – such as FMS – but also by new or improved approaches to manufacturing methods and organization, such as just-in-time. From this analysis, it becomes possible to develop a coherent and appropriate manufacturing strategy for the firm, which will provide the underpinning for meeting the key criteria in the business strategy.

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

One major requirement in this process is the implementation of a parallel organizational development strategy to ensure that the necessary degree of organizational integration is available to underpin these technical changes. Finally, the strategy can be implemented on a project-by-project basis, moving from "islands of automation" to full computer-integrated manufacturing. The advantage of this approach is that it permits the lower cost and risk features of an incremental philosophy to be retained but moves the firm forwards within an integrated framework.

This approach provides a rationale for making choices and avoids the risk of expensive and inappropriate systems being installed. The process can be summarized in the following five-stage checklist:

1. Identify business goals and strategies
 - What business are we in and why?
 - Where are we going to be in five years time?
 - How are we to get there (diversify, acquire, etc.)?
2. Identify relevant product strategies
 - Which markets or segments are we aiming for?
 - What will determine the competitiveness of our products?
 - How far do costs have to fall, quality to rise, etc.?

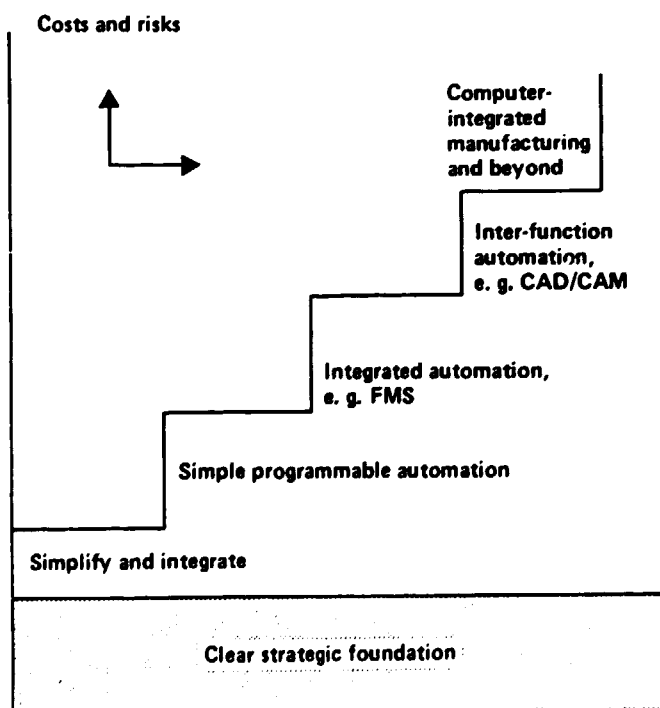
- What will customers be looking for in five years' time ?
 - What volumes and changes do we expect ?
 - What should be the level of customization vs standardization ?
 - What are external trends in competitors' products, technologies, etc. ?
3. Define manufacturing strategies
- What do we need to do to make products with the price non-price factors identified above ?
 - What implications does this have for :
 - Processes in use
 - Plant and facilities
 - Human resources
 - Work organization
 - Control and information system
 - Suppliers
 - Etc.
4. Define integrated operating strategies
- What strategies do each of the key functions – marketing, design, manufacturing etc. – need to perform in support of the above ?
 - How can these be integrated so that they support each other?
5. Define systems and automation strategies
- What systems are available which can contribute to these targets?
- Selection of technology (broadly defined) to meet the clearly identified needs – automation ? Just-in-time ? Reorganization ?
 - Build up to CIM on a multi-level basis, especially with regard to the information system within and between these levels which will act as the nervous system of the organization as a whole.

1.13 A step-by-step approach to implementation

Following such a strategic analysis, the next task is to begin actual implementation. Here the key lesson is that projects of this scale succeed where there is some form of phased implementation – a step-by-step strategy. Components of this include the use of pilot projects and simulation and a recognition of the value of the learning process so that time to assimilate and build on such learning is allowed in the overall project plan. A key benefit of this approach is that it avoids the “big bang” risks of high cost and complexity, as indicated in figure 8.

Figure 8

Step-by-step strategy for CIM



The same step-by-step philosophy can also be applied to the introduction of just-in-time total quality programmes; for example, Schonberger suggests a 17-step process moving from simplification and the focus on the customer to more advanced applications.

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1.14 Summary

It is becoming increasingly clear that there is no universal definition of CIM but, rather, that it involves a broad range of activities associated with the evolution of more efficient and effective manufacturing. Certainly, it makes extensive use of automation technologies, especially in their more integrated forms (such as CAD/CAM or FMS), but it also involves extensive change in traditional approaches to structures, functions and culture within manufacturing organizations. It is also characterized by a gradual convergence of both these streams towards a highly integrated facility which opens up considerable potential for new and more effective ways of manufacturing.

There is as yet no fully-developed CIM facility in the world, although there are a variety of experiments and successful applications of integrated installations moving towards full CIM. Moving to CIM involves long time scales and requires a strategic approach to selection and implementation, which not only fits the long-term business plan but also allows for the considerable organizational learning needed successfully to assimilate and exploit such technical and organizational changes. CIM is emphatically not a "plug-in" solution or a quick but expensive

technological "fix," and the experience of firms which have approached it in this manner has generally been disappointing.

Evidence from early users stresses the importance of organizational changes in achieving the full potential offered by CIM. In many cases, successful users of CIM report that the majority of the benefits – sometimes as much as 70% or 80% – came from organizational changes rather than from the expensive new systems which they had purchased. Experience of this kind suggests that there is much to be gained by adopting a step-by-step strategy. Beginning with changes to organization and management and gradually moving into more advanced applications of integrated automation is the most effective. Such a "simplify, automate, computer-integrate" strategy has particular attractions for manufacturers in developing countries since it is not a capital-intensive approach, but stresses instead investment in and development of human resources.

It can be argued that there is a transition in progress from capital-intensive manufacturing to knowledge-intensive manufacturing, where the key resources are the knowledge, skills and experience which a firm possesses and its ability to mobilize the creativity of its staff to enable it to function as a highly adaptive, learning organization. (For example, in recent years, the level of investment in R and D in Swedish engineering firms has been much higher than the level of capital investment.) The key to effective exploitation of the opportunities offered by computer-integrated manufacturing is to ensure that it is located within such an adaptive and flexible organizational environment.

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OVERVIEW OF PAPERS PRESENTED AT THE SEMINAR ON COMPUTER-INTEGRATED MANUFACTURING

In his opening address to the Seminar on Computer-Integrated Manufacturing, Theodore Malloch, the Senior Advisor to the Executive Secretary of ECF, highlighted the new challenges facing the manufacturing industry, pointing out that recent years had seen a new rallying call, of "automate or evaporate!" Firms were increasingly recognizing the need to take a more strategic approach to manufacturing and to employ the powerful technologies available within the CIM framework to reduce lead times, improve quality, enhance equipment utilization, reduce inventories and provide a much higher level of flexibility, responsiveness and service to customers.

Reviewing the experience so far and setting the agenda for the Seminar, he suggested that discussion could usefully focus on a number of key questions including:

- What is meant by CIM?
- Where is the technological frontier?
- What have been the achievements in industry in moving towards CIM?
- What are the principal obstacles?
- How can industry prepare itself for CIM?

These themes were explored throughout the Seminar in presentations and discussion, and the papers which follow represent a sample of this. Part one provides two useful overviews of trends and experience in CIM in both the industrialized and the developing world, and stresses some of the key challenges and opportunities which this new manufacturing environment offers. In both these papers, and in the discussion at the Seminar, the discontinuous nature of the changes involved in CIM emerges clearly. Not only is the physical technology opening up exciting new opportunities by virtue of the integration of previously separate functions in the manufacturing business, but at the same time there is a dramatic challenge to traditional roles and structures within manufacturing organizations. In particular, the importance of developing human resources to provide the necessary flexibility and creativity to operate "knowledge-intensive" CIM factories was stressed.

For both developing and industrialized countries alike, the challenge to move to a different approach to

manufacturing is clear. The emphasis on organizational change and development of human resources as a prerequisite for successful CIM programmes effectively changes the nature of the barriers to entry, since the requirement is not solely for capital investment but also for managerial and organizational development. Learning to use physical and human resources in new ways will become as important a competitive resource as possessing the latest state-of-the-art technology.

The paper by M.E. Merchant provides a clear picture of the long-term evolution of CIM and its gradual convergence from early developments in the 1960s. In particular, he highlights the emerging need to take a system view of the whole organization, moving attention from narrow considerations of the efficiency of particular operations or machines and towards the overall effectiveness of the business as a whole. As he comments, CIM "...demands a wholly new approach to the operation of manufacturing." He sees the future as involving two key trends – the development and implementation of new and integrated technological approaches and the parallel development and implementation of new managerial approaches, "...both of which are essential to arrival at the new and highly beneficial way of operating which constitutes CIM." He goes on to explore these two strands, looking particularly at artificial intelligence and simultaneous engineering on the technical side and at education and training, organizational structures and the need for new financial management tools on the organizational side.

This theme, of simultaneous technical and organizational development is echoed in the paper by L. Pineda-Serna and D. Chudnovsky, which focuses on the opportunities which CIM may hold for developing countries. He describes a proposed UNIDO project which would provide support in terms of training and advice to enterprises aimed at taking a strategic approach to CIM, gradually moving from organizational changes and product process redesign via a step-by-step automation strategy towards full integration.

Part two provides a closer look at the experience of CIM diffusion and particularly the experience with component technologies such as flexible manufacturing systems (FMS). This includes reports from a major international comparative research programme being co-ordinated by the International

Institute for Applied Systems Analysis (IIASA), which now provides a valuable database of experience in a variety of countries. These studies address themselves to questions of costs, benefits, problems and wider implications of CIM. Points raised in these papers are echoed in those covering experiences (including successes and failures) in the United States, Japan, Western Europe and the USSR.

The first paper in part two, by the late Iouri Tchijov, brings out some of the rich data resource which he carefully husbanded in the IIASA database of flexible manufacturing systems. This collection of detailed information on over 800 flexible manufacturing systems worldwide provides us with a clear indication of some of the important diffusion characteristics associated with a key CIM component. His paper underlines the multivariate nature of the driving forces behind CIM, stressing that these are not confined to cost reduction but also include increasing emphasis on variety, product quality and overall delivery responsiveness. The data also suggests that there is increasing choice opening up for potential users, with different system types becoming available to suit various batch size and other market-related requirements. Across this spectrum of applications, the experience of benefits is impressive, with considerable improvements in performance on key competitive criteria such as set-up time reduction (and hence the ability to handle smaller and more varied batches), inventory saving and lead-time reduction (making possible shorter delivery times to customers).

These themes are elaborated further in the paper by Ranta and Tchijov, which discusses costs and benefits and highlights in particular the emerging split into two different system types, one of which is a small-scale "compact" system suited to smaller company application. Early evidence suggests that this is often the most cost-effective configuration of CIM.

International differences are, however, evident, with some firms and countries able to exploit such technology to much greater advantage than others. This brings in the important question of context – that simply buying FMS or other elements of CIM technology is only a part of the story. As Maly points out in his paper, the strategic drivers and the organizational context in which FMS is introduced varies widely – for example, in his comparison between Finland and Czechoslovakia. He highlights the differences in the strategic justification for investments, with greater emphasis on flexibility on Finland, and the options which exist between what might be termed "techno-centric" systems which rely heavily on hardware and software to deliver their

flexibility and "anthropocentric" systems which build upon the inherent flexibility of human operators as a key interface between different system components.

Baranson extends this discussion by looking at Japanese, European (especially in the Federal Republic of Germany) and East European experience and contextual arrangements and suggests that these go a long way towards explaining relative differences in performance of CIM. This point is given further support in the paper by Glazev, which provides detailed data on experience in the USSR and suggests that, despite widespread availability of CIM technology from the supply side (as a result of the operation of a "command economy"), much of this equipment is poorly utilized as a consequence of inappropriate organizational and inter-organizational arrangements. He suggests that there is an urgent need for attention to be paid to this component.

Mieskonen discusses the case of smaller market economies, using the example of FMS experience in Finland and drawing out lessons for other, similar economies such as Sweden, Austria and Czechoslovakia. Significantly in his discussion of factors promoting and hindering successful change, he highlights the value of earlier experience with NC-technology – essentially underlining the value of a step-by-step progress. He argues for the use of FMS as a tool to enable firms in such economies to be more flexible and responsive at a strategic level – but also warns about the necessity of changing the whole system in order to obtain these benefits. As he puts it, "don't buy a sports car if you are afraid of driving at high speed!"

A key theme in all these papers is the growing awareness of the need for major structural changes in institutional frameworks within and beyond the firm if the full potential of CIM is to be unlocked successfully. This question is specifically addressed in part three, which focuses on organizational and managerial aspects of implementing CIM. Here the striking message, in papers covering experience in Japan, the United Kingdom and an overview of work in the factory of the future, is that the same points emerge. This lends considerable support to the view that our old models of factory organization and management, based upon the principles of Frederick Taylor and Henry Ford, are becoming increasingly inappropriate and that new models are needed in the era of CIM. Whilst it is not yet clear what the blueprint for the new factory organization of the future will be, it is likely to involve a much greater emphasis on teamwork, on decentralization and networking, on minimizing hierarchy and on

developing flexible human resources within a problem-solving and learning culture.

The paper by Yamashina and colleagues does much to dispel the myth that Japanese success is due to high levels of diffusion of very advanced computer-based equipment. Although CIM is recognized as an important long-term target, most Japanese manufacturers are concerned with integration rather than computer-integration, stressing that much can be achieved through organizational changes and through step-by-step improvements using relatively simple and proved automation technology.

Paul Simmonds takes this theme further, suggesting that the kinds of organizational change now being required provide a very different design blueprint to that which operated in older manufacturing times. His discussion of the key parameters of change – flatter hierarchies, closer functional integration, multi-skilling, network relations between firms, etc. – are all themes which also come through in Karl-Heinz Ebel's paper, which focuses on the central importance of new skills in the factory of the future – and the need for radical changes to training and development systems to provide the lubricant for moving to a new model of manufacturing.

Part four explores some of the more technical issues and focuses on experience at the integration frontier, as firms try to integrate components of CIM into a broader framework. Once again, the issue of a long-term strategic framework within which smaller step-by-step increments can be located is very much in evidence. Mårtensson, for example, provides a road map for such changes and describes work in Sweden based on using artificial intelligence principles to assist in the key task of software integration within and between elements in a manufacturing system. Tomancok gives a practical view based upon experience in the Siemens AG plant in Vienna, where the model used was essentially a modular, step-by-step development process, rising from the development of individual cells through a hierarchy of integration.

Kovacs reports on Hungarian experience with two pilot plants proving out some of the integration issues involved in CAD and CAM. Both these plants were designed with a modular, step-by-step philosophy, using network principles to provide the later and higher level links in the integration hierarchy. Belitz and Weber concentrate on software strategy, which is perhaps the key current problem in the technical development of CIM. Their analysis suggests again a total system built up in modular fashion, and it also introduces the important questions of standards to

facilitate networking and system building, and the need for co-operative development between users and suppliers of software.

The paper by Dato in part five covers the important question of standards – the need for some form of electronic "highway code" to regulate the increasingly complex and confused amount of electronic traffic which will be running around the factory automation networks of the future.

A number of themes emerged repeatedly throughout the Seminar. First, that there is no clear definition of CIM but that it does represent much more than a single narrow technology. It is more of a concept or philosophy, providing a blueprint for the emerging factory of the future. Related to this is the clear message that CIM has yet to arrive at its fully developed form, although there are a number of advanced experiments in various countries moving towards this goal. The road to CIM is still blocked by a series of obstacles, including technical problems (especially in software), the need for standards and the need for a major rethinking of managerial and organizational systems within which to exploit CIM technology.

The second key point is that the very high cost of CIM equipment, coupled with the scale of these problems, means that any firm wishing to enter the field must view CIM as a long-term strategic exercise, which involves setting up a broad framework and then moving towards the CIM goal in a series of planned integrative increments – a step-by-step approach. Attempts to make the move by some form of "quantum leap" have almost all ended as costly failures or as cases where expensive and powerful technology is performing sub-optimally.

From this, some valuable guidelines for industries wishing to move into CIM can be derived. In particular, preparation for the introduction of CIM requires:

- Reappraisal and reorganization of production, planning and managerial systems
- Investment in the development of human capital, to provide the necessary flexibility and to establish a continuous learning and improvement culture. Training should be seen as a strategic investment, not a cost
- Design of new work and career structures which will ensure involvement and commitment of employees to the strategic goals of the enterprise. Again, this requires a shift in perspective, from

viewing people as a necessary cost to seeing them as a key resource

- Extension of this process of change towards more integrated modes of organization and operation to areas beyond the enterprise, in the supply and distribution chains, in contact with customers, etc.
- Development of financial appraisal systems for investment justification which take a strategic view of new technology and consider its contribution to overall effectiveness of the business rather than

concentrating too narrowly on improvements in efficiency of particular equipment or functions

- Adoption of a long-term strategic perspective which identifies clear business goals and a manufacturing strategy to support their achievement. Such a manufacturing strategy will involve components of organizational and technological change and should provide the framework for a phased, step-by-step process of development of CIM.

PART ONE

GENERAL TRENDS IN THE DEVELOPMENT

AND IMPLEMENTATION OF CIM

CIM – ITS EVOLUTION, PRECEPTS, CONCEPTS, STATUS AND TRENDS

by M.E. MERCHANT, Advanced Manufacturing Research, Metcut Research Associates Inc., Cincinnati, Ohio, United States

INTRODUCTION

Computer-integrated manufacturing (CIM) is not an improved methodology for carrying out conventional manufacturing. Instead, in its ultimate state of the art, it is a wholly new approach to the operation of manufacturing in its entirety. To appreciate this fact it is necessary to understand the nature of its evolution. The evolution of CIM to its current state of recognition, acceptance and application, incomplete as it is, has nevertheless already been a protracted endeavour. The evolution can be said to have had its beginnings in the advent of the computer-related technology of the numerical control of machine tools in the 1950s. That proved to be a watershed event, and for several reasons. First, it gave birth to capability for flexible, programmable automation of manufacturing. Even more importantly, however, it began the slow process of opening our eyes to the tremendous overall potential inherent in computer technology to make manufacturing far more capable and productive than had even been dreamed possible. Finally, and most importantly, it provided a means for beginning to incorporate intelligence into manufacturing, initiating the process of freeing manufacturing from being wholly dependent on an external presence, namely, the human being, for its successful operation – a trend now beginning to bear real fruit today.

As a consequence of this initial impact of computer-related technology on manufacturing, the decade of the 1960s saw the development of an entirely new concept and understanding of the nature of manufacturing and its technology. That concept and understanding derived from the fact, which

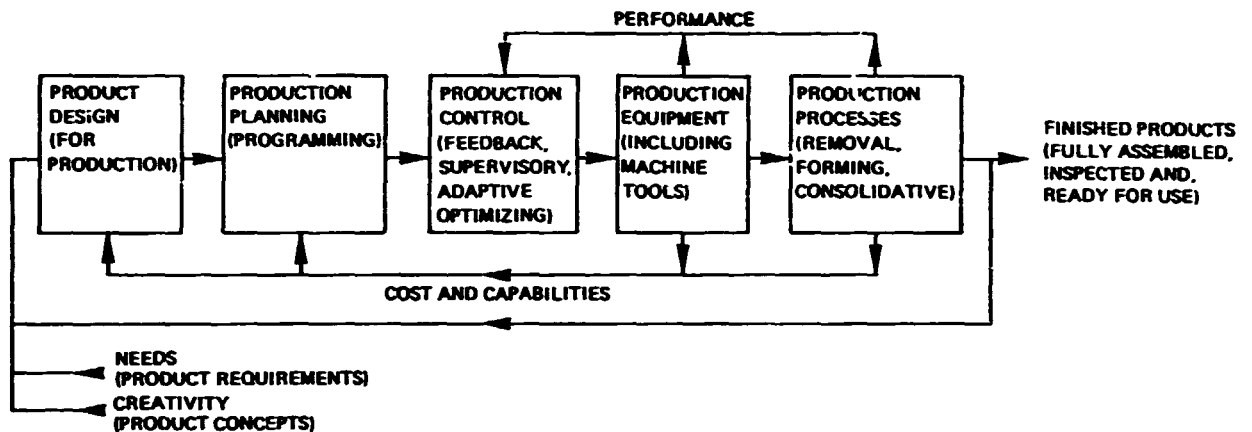
became increasingly evident during the 1950s and 1960s, that the digital computer is, innately, a systems tool. As such, when the computer began to be applied in actuality, manufacturing is not just a collection of various types of activities and processes but is instead a system – a system for creating discrete products useful to man.¹ The concept and understanding of the nature of manufacturing which resulted from this awakening can be expressed in the form of three precepts, namely:

1. Manufacturing is a system, the input to which is the conceptual modeling of a product and the output of which is a successfully performing product, and it should thus be operated as such a system.
2. The prime objective which must be satisfied in the operation of that system is that output be maximized relative to input.
3. The prime condition which must be satisfied if that objective is to be accomplished in full is that all the elements of that system be integrated.

Now the world of manufacturing was confronted with a new concept and understanding of manufacturing – namely that manufacturing is a system – and also with the dawning realization that the computer, as a systems tool, held the *potential* to *operate* manufacturing as an integrated, flexibly-automated, self-optimizing system. It was the combination of these two elements which led, during the 1960s, to the emergence of the concept of computer-integrated manufacturing (CIM), and the computer-integrated manufacturing system.^{2, 3} The concept which emerged at that time is illustrated in Figure 1.

Figure 1.

Concept of the computer-integrated manufacturing system, 1969.



Although the wealth of technological concepts and possibilities – those of programmable automation of manufacturing, the systems approach to manufacturing, computer-integrated manufacturing, the CIM system, and the intelligent manufacturing system – which came into being in the decade of the 1950s and 1960s – had tremendous implications for intelligent manufacturing, these implications were far from being grasped immediately by the world's manufacturing industry, by the great majority of manufacturing engineers, and even by some manufacturing researchers. Thus the predominant trend during the decade of the 1970s was one of slowly dawning recognition, evaluation, and clarification of these concepts and possibilities and of their extraordinary potential for improvement of manufacturing productivity, quality, timeliness, and cost-effectiveness. Therefore, only those companies and manufacturing engineers who were technological leaders accomplished much in the way of significant application of the CIM-related technologies in practice during the 1970s.

The decade of the 1980s has, however, begun to see the recognition by the manufacturing industry of two essential facts concerning CIM, namely, the fact that it demands a *wholly new* approach to the operation of manufacturing, and the fact that it offers enormous potential to improve manufacturing capability and

cost-effectiveness. This realization, which is the essence of the *status* of CIM today, is resulting in a major, two-pronged, world *trend*. That trend is toward realistic and substantial accomplishment, in industry, of full computer integration of the system of manufacturing. The first of its two prongs is dedicated to development and implementation of new and integrated *technological* approaches to products and processes and the second to development and implementation of new managerial approaches to the operation of manufacturing enterprises, both of which are essential to arrival at the new and highly beneficial way of operating manufacturing which constitutes CIM. This overall two-pronged trend is marked by important corollary trends which fall into two main categories, corresponding to the nature of its two prongs, namely, *technological* and *managerial*. Let us, therefore, now explore the promise and status of the corollary trends that lie in these two main categories.

TECHNOLOGICAL TRENDS

Although there appears to be a welter of technological trends at work in the development and implementation of CIM, my observation of the international scene has led me to the conclusion that two *developing* trends stand out from others with respect to their importance for the future of CIM. The first of these, in my opinion, is the developing

trend toward accomplishment of powerful capability for so-called "*simultaneous engineering*" – simultaneous engineering of the conception and design of a product and of the planning and execution of its manufacturing production and servicing. This developing activity goes by many different names, such as concurrent engineering, life-cycle engineering, design fusion, integrated and co-operative design, design for manufacture, etc. The second important developing trend, in my opinion, is that toward the evolution of artificial intelligence (AI) in the manufacturing system. This has such technological facets as *expert systems*, "*smart sensors*" and *neural networks*.

Simultaneous Engineering

There are at least two highly potent main driving forces toward accomplishment of powerful capability for simultaneous engineering, namely, reduced product costs and increased industrial competitiveness. Regarding costs, it has been demonstrated many times that over 70 per cent of the cost of the manufacturing production of a product is fixed when its design is completed and "frozen."

Full capability for simultaneous engineering will make possible the reduction of that cost of manufacturing production to an absolute minimum by accomplishing the design of such production before the design of the product is completed and frozen. Of course, it will also effect other cost savings, such as the elimination of design changes conventionally found necessary for practical manufacture and servicing of the product. Regarding industrial competitiveness, the tremendous shortening of the lead time between conceptual design of a product and its commercial production, potentially possible through accomplishment of full capability for simultaneous engineering, promises major increases in industrial competitiveness for the world market for manufactured goods.

Full capability for simultaneous engineering is still a long way from being accomplished due to technological hurdles which must still be surmounted. However, much progress toward it has already been made using today's state-of-the-art CIM technology. As an example, Fanuc Ltd., of Japan, has made its Product Development Laboratory the instrument for accomplishing its simultaneous engineering of all its new products, utilizing such state-of-the-art technology. Taking the conceptual design of its new products from its Basic Research Laboratory, the Product Development Laboratory is able, by use of current capability for simultaneous engineering, to

launch the commercial production of that product within a period of six months to one year.

Artificial Intelligence

As was so aptly set forth by our former CIRP colleague, the late Jzef Hatvan, ⁴ the major potential of artificial intelligence for the manufacturing system, still *very far from being realized*, is that of capability to overcome the problems created by the fact that that system is not, and can never be, a totally *deterministic* system. He made clear the fact that AI has the potential, when developed far beyond its present state of the art, to transform the non-deterministic system of manufacturing into an intelligent manufacturing system which is "capable of solving, within certain limits, unprecedented, unforeseen problems on the basis even of incomplete and imprecise information" – information characteristic of a non-deterministic system.

Closer at hand in the field of AI are the problems which must be dealt with in the development of the science and technology necessary for reaping the full benefits of utilization of expert systems, smart sensors and neural networks in the manufacturing system. Such developments are necessary steps toward realization of the intelligent manufacturing system envisioned by Hatvany. Research such as that being done by Lu ⁵ and his associates in the Knowledge-Based Engineering Systems Research Laboratory at the University of Illinois, and Ayres ⁶ and his associates in the Department of Engineering and Public Policy in Carnegie-Mellon University, provides examples of pioneering work in this field.

Lu's work is highly relevant to *expert systems* and AI in general. He describes the research on knowledge processing for engineering automation which is being conducted in his laboratory as being aimed at investigating means of processing knowledge into a useful commodity, rather than studying ways of processing materials into useful products. These studies are focused on how knowledge, in various forms, can be effectively engineered into more appropriate forms for better utilization and on fundamental methodologies that can help engineers intelligently harvest and apply knowledge for engineering automation. The goal is to develop and implement knowledge-processing techniques needed in the development of highly automated engineering systems and to meet the challenges of the upcoming knowledge-intensive industry.

Ayres and his associates are addressing the problems of *smart sensors*, having artificial intelligence, as

decision-makers in the manufacturing system. They are looking particularly at factory-floor activities. Here we are already beginning to see a rather rapidly increasing replacement of flexible human workers having "high quality sensory interpretative abilities" by smart sensors having some degree of artificial intelligence. However, as Ayres and his associates note, such "adaptive control" is "severely constrained by the capabilities of existing sensors and interpretative computer software, especially the latter." They find that the generalized capabilities needed for the future, currently beyond the state of the art, are "(i) sophisticated machine or tactile systems, (ii) complex decision algorithms, and ultimately (iii) an ability for the supervisory system to learn from experience." This requires that the introduction of AI into the overall manufacturing system, to unlock the door to CIM, must be preceded or accompanied by the availability of such smart-sensor (sensory-information) processing capabilities. Their research on the economics of such machine vision taction has shown that such developments "should not be assessed in the narrow context of specific tasks in direct competition with human workers by as hitherto missing links that will permit all the elements of the factory of the future to communicate effectively with each other so as to function as an organism rather than as a set of independent cells" - a true CIM system.

Technology for co-ordination, or "fusion," of the outputs of multiple smart sensors to accomplish such integration as that characterized above is also virtually in its infancy. One of the most promising technologies for accomplishing sensor fusion, recently appearing on the scene, is that of *neural networks*. These are attempting to duplicate the human neural network, which accomplishes such fusion with ease, with computer simulation. Resulting neural network computers embodying the current state of the art are already exhibiting significant capability for dealing with pattern recognition problems in a noisy environment or where there is a level of uncertainty about the signal - conditions obviously found on the factory floor. Initial efforts to harness such capability tend, of course, to tackle a considerably smaller segment of the manufacturing system than that represented by the entire factory floor. An example of such efforts is the research being carried out by Aggarwal⁷ and his associates at Metcut Research Associates on adaptive control of grinding. Past efforts on such controls have typically employed only a single sensor. The Metcut approach is to monitor four different types of signals, namely, acoustic emission, grinding power, wheel-workpiece normal force, and vibration. This requires fusion of the

output of all four of these sensors. A neural-network concept is therefore being considered, and is one which, if feasible, should also be transportable across the whole field of machining processes.

MANAGERIAL TRENDS

Although, again, there is a great variety of managerial trends at work in the development and implementation of CIM, my observation of the international scene has led me to conclude that the most important of these are of four main types, namely, trends in the organizational structure of manufacturing companies, trends in the professional role of manufacturing engineers, trends in education and training of manufacturing engineers and workers, and trends in the justification of CIM-related capital investment.

Organizational Structure

The prime factor which must be kept in mind concerning CIM-related organizational trends is that computer-integrated manufacturing is a wholly new approach to manufacturing - a systems approach - and so requires a systems approach to the organizational structure of a manufacturing company. In the past, in the absence of computer technology and its tremendous capability to provide on-line communication of data and information throughout a company, we were all dependent on direct human-to-human verbal and written communication - with all its difficulties, inefficiencies and errors - to operate manufacturing. As a result, the organization of conventional manufacturing has tended to be made up of "walled-in" local "empires." With the arrival of computer-based capability for flexible automation of both the hard and soft components of manufacturing operations, this organizational structure led to the creation of "islands of automation" based on the local "empires," with almost no consideration being given to how these "islands" could be interfaced and integrated with each other. This situation has created a real impediment to integration!

Ways of surmounting this impediment have, however, now been found. Companies which are most successful today in carrying out true manufacturing systems integration have found that the "local-empires" type of organization is incompatible with accomplishment of such integration. Instead, they have found that what is required, as stated above, is the establishment of a systems approach to organization. Further, they have found that the key ingredient of such an approach is the use of *team*

management and *team-based* operations, founded on the establishment of *co-operative relationships* among all of the company's personnel. Thus the major organizational trend being pursued today by those manufacturing companies striving to implement CIM effectively is that toward establishment of a systems approach to organization and toward utilization of team management and team-based operations, founded on establishment of co-operative relationships.

In pursuing the development of such relationships, they have found the most useful technique to be the creation of project teams made up of representatives of the various departments that contribute to the overall manufacturing activity within a company, from product design to finished product. The co-operative-relations approach is necessary, and is also effective, because of the fact that, in a true systems approach to manufacturing through CIM, the actions of each department (and, in fact, of each individual) interact with those of all the other in the system to produce the big payoffs. The trend toward application of this systems approach to organization and its team-centered techniques is a growing one throughout the world today, in progressive companies, and is certainly a salutary development.

Professional Role of Manufacturing Engineers

In recent years it has become increasingly evident that the overall international trend toward implementation of full CIM in practice is generating a major change in the role of the manufacturing engineer in all of his or her professional walks of life. This trend has recently been the object of a study by the Society of Manufacturing Engineers, the findings from which are contained in a 1988 report.⁵ The principal findings fall mainly into two categories, namely, the *nature* of the newly developing role and the *changing emphasis* in the manufacturing engineers's manner of working.

The SME study sees the nature of the newly developing role of the manufacturing engineer as consisting of three distinct and different roles, with no one individual person able to play all three. It identifies and characterizes these roles approximately as follows:

1. **Technical Specialist.** The "conventional" manufacturing engineer as we've known him or her in the past, focusing on a specific technological aspect of the manufacturing system in considerable detail.

2. **Operations Integrator.** Playing a central role and interacting with almost all functions within the manufacturing system.

3. **Manufacturing Strategist.** Influencing the entire manufacturing system to implement worldwide strategies.

While this characterization of the nature of the newly developing roles or role of the manufacturing engineer corresponds with my own, my experience and my observation of that of others around the world has led me to the conclusion that the three are not separate career paths, with no one person able to follow all three. Instead, a truly professional manufacturing engineer is, more and more today, finding that he must progress through at least the first two roles during the course of his career, and in many cases, through all three.

The SME study sees the *changing emphasis* in the manufacturing engineer's manner of working to be mainly of three types. The first of these is a shift from working individually to working as a member of a team of people having various types of backgrounds and responsibilities in the organization. This trend, of course, corresponds precisely to that of the trend toward creation of the multi-disciplinary project teams described in the preceding section on Organizational Structure. The second type of changing emphasis seen by the study is that of a gradual broadening of the scope of the manufacturing engineer's work so as to encompass not only technological factors but also the human factors and human consequences of application of that technology. This is, of course, a natural consequence of the broadened horizons provided by a systems view of manufacturing in place of a "bits and pieces" view. The third type of changing emphasis seen by the SME study is an increase of the use of outside services by the manufacturing engineer to supplement his or her capabilities. This trend, which I do not find to be as significant as the other two, is nevertheless, also a natural consequence of the manufacturing engineer's broadened horizon provided by a systems view of manufacturing.

Education and Training

The prime CIM-related trend affecting the education and training of manufacturing engineers and workers today results from a new trend in the nature of the work to be done in CIM factories. Today, this work is beginning to consist more and more of the *intellectually challenging*, satisfying type which computer-integrated and automated systems offer – and less and less of *physically taxing* manual work.

Thus what is increasingly required are skilled *knowledge* workers rather than skilled *manual* workers. Education and training for CIM needs to be targeted at producing an adequate supply of such, from technicians to highly qualified engineers.

A significant consequence of this trend is a growing by very marked change in the university educational programmes for manufacturing engineers, worldwide. These include not only the programmes for initial education, but also the equally important programmes of continuing education so necessary to keeping up to date with the rapidly advancing technology. Today, all of these are rapidly evolving into programmes of manufacturing *systems* engineering education, or education for CIM. The developing characteristics of these reflect all aspects of the trends in the development and application of CIM discussed in this paper. First of all, as implied above, their focus is shifting away from the "bits and pieces" view of manufacturing toward a systems view, in keeping with the overall trend occurring in that development, discussed early on in this paper. Secondly, they are incorporating more and more of the changing manufacturing systems technology discussed earlier, such as simultaneous engineering and artificial intelligence – particularly the closer-in facets of the latter such as expert systems and smart sensors. They are also being tailored to reflect the changing role of the manufacturing engineer and the need for him or her to be able to progress from the role of technical specialist to operations integrator and manufacturing strategist during the course of his or her career. They are also beginning to focus on the manufacturing engineer's need for capability to work effectively as a member of a multi-disciplinary team and to deal with the human factors and human consequences of the application of CIM, discussed in the previous section.

Justification of Capital Investment

Today, many manufacturing companies are experiencing increasing difficulty in satisfactorily justifying capital investments as they move into implementation of CIM-related technology. Such difficulty arises primarily from the fact that, in the past, the approach to justification of investment in capital equipment has been to rely very heavily on calculation of return on investment (ROI) based on discounted cash flow (DCF), using experience-tested techniques. Unfortunately, however, when this traditional approach is used as the sole basis for trying to justify investment in CIM hardware and software, it can often lead to false conclusions. The basic reason for this is the fact that CIM technology is quite different from conventional manufacturing technology

and so requires departures from the traditional methodology of justification. The required departures are primarily of two kinds. First, as pointed out by Kaplan,⁹ the traditional DCF analysis needs to be modified in many ways from the experience-tested techniques of the past to take account of the realities of ROI obtainable with CIM's unique kinds of payoff capabilities. Secondly, however, even the best such efforts at modification of ROI techniques have not been able, as yet, to find a way of quantifying all of the subtle payoffs which stem from certain performance factors which play a much larger role in computer-integrated manufacturing than in conventional manufacturing. Such factors include:

1. lead time reduction
2. capability to economically produce great varieties of products in small – even one of a kind – lot sizes (*process flexibility*)
3. capability to easily accommodate product design changes (*product flexibility*)
4. insurance of high and reproducible *product quality*
5. greatly increased capability for *on-time shipment*
6. greatly *reduced uncertainty* in overall operations
7. greatly increased ability to formalize, employ, and retain *expert knowledge* in manufacturing
8. enhanced ability to meet *environmental and occupational hazard requirements* economically.

All of these, and more, are much more readily obtainable through computer-integrated manufacturing than in conventional manufacturing. All can offer major economic payoffs. They will result in:

1. ability to respond very swiftly to changing *market demands*
2. ability to economically *customize products* to match a variety of customer needs and desires
3. increased *competitiveness*
4. increased *market share*
5. reduced *warranty and sales costs*.

How does one quantify the relationships between such factors and such results, or even the specific payoff to be expected from them? In some cases, they are just not quantifiable. Yet such factors and results can be absolutely critical to the economic well-being and survival of a manufacturing company today. Thus, the bottom line is that justification of investment in CIM cannot always be arrived at by purely quantitative means. In such cases, justification of investment *must* be arrived at by *strategic*

decision-making involving both quantitative and non-quantitative factors. A company must then, in such instances, prepare its own listing, prioritized, of the strategic factors, both quantitative and non-quantitative, most critical to its own economic well-being and survival, for use in the strategic-decision-making process of justification of investment in CIM. That listing should then be used as the basis for arriving at its CIM investment decision. The trend toward utilization of such a strategic approach to justification of investment in advanced manufacturing technology is one which is growing rapidly throughout the world today, in progressive companies, and is paying them handsome dividends.

CONCLUSION

Despite its enormous potential to improve manufacturing capability and cost-effectiveness in world industry, the reduction to practice of the concept of computer-integrated manufacturing has moved disappointingly slowly in the more than 20 years since it came into being. However, the current, newly-developing trend in world manufacturing industry toward realistic and substantial accomplishment of full computer integration of the system of manufacturing shows great promise of changing that situation significantly for the better. The two-pronged nature of that trend, resulting in the generation of both technological and managerial corollary trends of a very substantive nature, lends great strength to that promise. Therefore, I believe we can look forward with renewed confidence to seeing that reduction to practice march ahead considerably more rapidly and confidently than in the past. This indeed bodes well for the future economic and social well-being of the world's people.

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PLANNING AND PROGRAMMING THE INTRODUCTION OF INDUSTRIAL AUTOMATION TECHNOLOGIES IN THE CAPITAL GOODS PRODUCTION OF DEVELOPING COUNTRIES

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The development and diffusion of new industrial automation technologies has started a new industrial revolution, the impact of which is already felt and which will become increasingly strong in the years to come. Because of the linkages that exist in the world economic system, this will have a profound effect on the industrialization process in all developing countries. The new technologies, especially those based on microelectronics and informatics, affect industrial development in two ways: through their impact as a manufacturing sector on its own and through their diffusion to other manufacturing sectors. As a sector of industry, the manufacture of microelectronic components and equipment and of machinery operated and controlled by electronic devices constitutes one of the key and most dynamic segments of the capital goods industries. Given the high research and development expenditures, the quick technological progress and the concentrated nature of the supply of many segments of the electronic and electronically controlled equipment industries, the barriers to entry into and to successful operation of developing countries in these segments should be analyzed in depth.

But, even without considering the issue of entering into the production of these technologies, it is extremely important to analyse in depth the impact of new industrial automation technologies on different manufacturing sectors. Given the fact that the new industrial automation technologies are especially suited for the production process of capital goods, it is very important to pay attention to the impact of these technologies in the capital goods producing industries in developing countries.

The production process of capital goods, especially those made in small batches, may be strongly influenced by the diffusion of industrial automation technologies based on microelectronics and informatics. These technologies not only tend to save labour, but also to provide other substantial benefits to firms applying them. If this diffusion is faster in industrialized than in developing countries, then the existing technological gap will widen and the competitiveness of machinery producers in developing countries will be reduced, in which case the anticipated share of developing countries in the global capital goods production is likely to be even smaller than current perspectives suggest.

* The designations employed and the presentation of material in this paper do not imply the expression of any opinion whatsoever on the part of the secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

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

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The actual and potential consequences of the new industrial automation technologies for the international division of labour and location of production are not well known. Still, there are reasons to believe that automation in many cases is a threat to further industrialization of developing countries and even to their present production of capital goods, due to factor-saving biases and cost reductions associated with the use of the new technologies. On the other hand, given the skill-saving character of some industrial automation technologies, they probably provide new opportunities, for the countries opportunities which they should try to exploit.

On the whole, relatively little is known about the specific threats and opportunities of the new automation technologies for developing countries.

The rationale for the present paper is actually to increase the knowledge on these issues in order to guide country and enterprise strategies and UNIDO support activities.

As a basis for the formulation of responses and strategies of developing countries, it is crucial that the impact of new automation technologies should be identified in very specific terms. It cannot be done at a general level, simply because the impact of the technologies differs between themselves as well as between the engineering branches for whose production they are used.

I. THE CONCEPT OF INDUSTRIAL AUTOMATION

With the tremendous progress made in microelectronics in the 1970s and 1980s, industrial automation has received a great push and entered into a phase of rapid technological change. In contrast with the traditional automation in which a chain of inflexible, special-purpose equipment was installed to deal with the mass production of relatively homogeneous products (e.g. motor cars), the new automation technology (called computerized or programmable) is flexible and applicable to a wide range of machine-building operations. Given the fact that the bulk of capital goods are made in small and medium-size batches, flexible automation has widened the scope of automation in the capital goods industries in a significant manner.

Rapid advances in microelectronics are the main driving forces in the new industrial automation technologies. The computer is a tool which is increasingly being applied in both the production

process and production planning. The challenge of the future will be to utilize computer technology in the manufacturing process from the moment of product conception, according to market information, to its final delivery to the customer. The success of this new concept of industrial automation will depend, to a large extent, on the capability and reliability of the information system and of the management which controls and supervises all processes.

A. Main components of the industrial automation technologies

Flexible automation includes a number of technologies such as those embodied in computerized programmable logical controllers (PLCs), computerized numerically controlled machine tools (CNCMTs), computer-aided design and manufacture (CAD/CAM), industrial robots and flexible manufacturing units (FMU), cells (FMC) and systems (FMS) that have been developed or drastically improved in recent years and are being diffused in a significant manner in the industrialized and in some developing countries.

Although the aim of computer-integrated manufacturing (CIM) is to link and integrate these different technologies to achieve system gains and, eventually, a factory in which the main functions are going to be fully automated, so far the main progress has been made in developing individual technologies and achieving partial integration, leading to "islands of automation" (CNCMTs assisted by robots; CAD/CAM for programming CNCMTs; linking several CNCMTs and robots in elementary FMS, etc).

While there is no doubt that PLCs, CNCMTs, industrial robots, CAD/CAM and FMS are crucial components of flexible automation, in some studies other technologies are also considered.

Sensors and actuators among process control equipment, automatic testing equipment, automated guided vehicles (sometimes included in FMS), production management systems (master production scheduling, material production planning, etc.) are sometimes considered components of industrial automation. Although some information is available on these technologies (see Camagni, 1988) attention will be paid below only to the leading flexible automation technologies, excluding PLCs (because they are mostly applied outside engineering industries).

On the contrary, automatic machines that are used in specific industries (like computerized textiles machines or NC sewing machines) are not generally included in

general studies of industrial automation, although they may be crucial for specific sectoral studies. In specific studies (for instance in the garments industry) the use of CAD applications are particularly relevant, as analyzed by Hoffman and Rush (1984) and Mody and Wheeler (1987).

The technologies included in flexible automation are generally process innovations and are applied as such in the user industries. However, they are product innovations for the firms making the equipment. These firms are generally engineering enterprises coming from a mechanical tradition but increasingly also industrial electronic producers.

1. CNC machine tools

In a CNC machine tool, the information needed for operating and controlling the machine is provided by an electronic unit (the CNC) rather than by the machine operator, as is the case with a conventional machine tool. Although the technology was developed in the 1950s, it was the introduction of the microprocessor into the control unit in the mid-1970s that led to massive diffusion of CNCMTs. The use of microelectronics has not only widened the range of functions that can be automated (e.g. tool changing, diagnosis of faults) but also led to a significant reduction in the prices of the CNC units (the price of a CNC unit in 1985 was four times lower than a unit developed in 1978, in constant prices and with similar functions (Chudnovsky, 1986) and, jointly with the changes in the economics of production of the machines, in the prices of CNC machine tools.

CNC machines are mainly metal-cutting machine tools and especially lathes, boring machines, milling machines, drilling machines and machining centres. In the case of metal-forming machine tools, applications have been limited mainly to punching and shearing machines.

The share of CNCMTs in the total production of metal-cutting machine tools increased from about 25% in 1976 to 76% in 1986 in Japan and 55% in Italy.

The diffusion of CNCMTs is explained not only by the maturity of the technology but also by the significant expansion of the user market. Small and medium firms have been adopting this technology as a result of its increasing reliability and declining relative cost. This is the case especially in Japan (Watanabe, 1983) and Italy (Camagni, 1988).

CNCMTs are mainly used in the machinery goods producing industries (specially in the branches that produce in small and medium-size batches), in aircraft production, in shipbuilding and in motor car and auto parts manufacturing. The adoption of CNCMTs greatly increases labour productivity and in some cases capital productivity also rises. The application of CNCMTs reduces the number of skilled workers as well as the skills required for operating the machines. Although some new skills are needed for programming, operating and repair and maintenance of CNCMTs, the net effect of introducing this technology has clearly been to save skilled labour (Jacobsson, 1986).

Of the technologies under consideration, CNCMTs are not only the most mature and diffused but also the technology of greatest economic importance. However, if only the CNC unit is considered, they are of lower economic importance than PLCs (programmable logical controllers), for instance.

CNCMTs have already being diffused in developing countries and, in some of them, local production is quite important. Estimated of the stock of CNCMTs in a number of developing countries (Argentina, Brazil, India, the Republic of Korea, Mexico, Singapore and Yugoslavia) are provided in Edquist and Jacobsson (1988, p.130). The largest stock in 1985 was that of the Republic of Korea (2,680 units in 1985). Given the high growth of that country's economy, increasing imports and local production of CNCMTs, it is evident that the stock has increased in a significant manner since 1985.

In Brazil (whose stock was 1,711 units in 1985), local production rose from 413 units in 1985 to about 800 units in 1987 (Tauile, 1987). In Argentina (whose total stock was estimated at 500 units in 1985), local production rose from 20 CNCMTs in 1985, to 34 units in 1986 and 109 units in 1987, of which 31 CNC lathes were exported, mainly to Brazil (information provided by AAFMHA, the machine tool producers' association). At the same time, imports grew from 13 units in 1985 to 20 units in 1986 to 44 units in 1987.

In the case of Mexico (whose stock was estimated at 500 units in 1984 in Edquist and Jacobsson, 1988), another study (Casalet y Morales Garza, 1986) estimated a total stock of about 1,000 units in 1985. It is very likely that many more units were incorporated in the more recent period. In Colombia, a recent study found that 61 CNCMTs had been incorporated up to the end of 1987 by twenty surveyed firms (Moreno, 1988).

In other Latin American countries with local production of capital goods, like Venezuela, Chile and Peru, it is likely that CNCMTs are also being diffused. A similar situation may be found in Asian countries, not only in China and the newly industrialized countries (NICs), but also in the ASEAN member countries and in other countries as well.

Further information on CNCMT diffusion and production in industrialized countries and in some developing countries is found in the studies made by Edquist & Jacobsson (1988), Jacobsson (1986), Chudnovsky (1985, 1986, 1988), Tauile (1987), Fransman (1986), Casalet y Morales Garza (1986), Watanabe (1983) and the Boston Consulting Group (1985).

2. Computer-aided design

CAD is an electronic aid for draughtsmen and design engineers. A CAD system is composed of a graphic workstation and some type of electronic processing device. Using these facilities, an operator can construct highly detailed drawings on line. CAD can be used in manufacturing industries but has wider applications in other activities like architecture and construction engineering services.

CAD systems are used to increase the productivity of designers and draughtsmen, shortening the lead time from order to delivery or from conception to production, and to perform work which is too complex for manual design and drawing (as is the case in the electronics industry for the production of integrated circuits) (Edquist & Jacobsson, 1988). It is clear that CAD systems mostly save skilled labour.

While at the beginning CAD systems were only based in large mainframes, in the early 1980s microcomputers and personal computers (PCs) started to be used in CAD systems. With PCs, CAD systems can be obtained at very low prices and hence this segment of the market will grow quickly and will include many small and medium-size firms. Prices have also been falling in big systems (from \$400,000 in 1980 to \$250,000 in 1985 (U.S. Department of Commerce, 1987).

In 1982 there were about 10,000 CAD installations in the world, of which half were in the United States and one third were in Europe. Most recent information (*Electronics*, January 1988 issues; Camagni, 1988) is quoted in values of shipments and, hence, it is difficult to have an idea of the number of installations.

CAD systems are used especially in the electrical machinery sector (particularly the electronics industry) and to a lesser extent in transport equipment and non-electrical machinery. With the recent reduction in prices, it is likely that applications in other industries will grow as well.

In robotics and CNCMTs, the early United States lead was lost to Japan, which is the leader in production and use. In contrast, in the case of CAD the supply is completely dominated by United States companies, with a relatively high degree of concentration.

CAD systems are being diffused in the NICs, especially in the Republic of Korea, Singapore, India and Brazil. In Argentina and Mexico there is also some diffusion of these systems and in Brazil, in addition to imported equipment, local production of both big and small systems has been fostered by the Government.

In the available studies, little information exists on the most recent patterns of diffusion, especially since the development of CAD software with a personal computer. (Further information in Edquist & Jacobsson, 1988; US Department of Commerce, 1987; Camagni, 1988; Tauile, 1987.)

3. Industrial robots

Although there are several definitions of robots, that of the International Organization for Standardization (ISO) is the most precise one:

The industrial robot is an automatic position-controlled reprogrammable multi-function manipulator having several degrees of freedom capable of handling materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks...

While this definition of programmable (by means of software) robots is similar to those used by the European and United States robot associations, the Japanese Industrial Robot Association (JIRA) uses a much wider concept including other automation devices like manual manipulators and sequence robots. In the narrow definition of robots playback, numerically controlled and intelligent robots are included. The intelligent robots differ from the previous ones by their sensory ability and capability to react to changes in the working environment.

The world population of programmable robots increased from 30,000 units in 1981 to 130,000 units in 1986, according to the ECE estimates (ECE, 1988). Although the annual growth rates in some industrialized countries have been very high, in other countries, like the United States, gross new orders of robots actually decreased in 1986, after a stagnation in 1985 (*International Herald Tribune*, 17 February 1989). Given this situation, some of the original forecasts (e.g. one million robots in use by 1990) have proved unrealistic.

Robots can be divided according to applications in:

1. Parts-handling robots;
2. Process robots (e.g. welding and painting robots);
3. Assembly robots.

Process robots account for more than half of the installations in the Federal Republic of Germany, half in the United Kingdom and one fourth in the United States. In the latter country almost three quarter of the robots are parts-handling. Spot welding is the leading process application in the Federal Republic of Germany and injections moulding is the leader in the United Kingdom and Japan.

Assembly robots, once technically relatively underdeveloped, recently started a process of quick diffusion once some technical problems were solved. (Edquist & Jacobsson, 1988, p.50).

Robots are being adopted for doing dangerous or unpleasant tasks, for improving quality and for upgrading the technological level of the firm, especially when other flexible automation technologies are used. In terms of labour, robots largely replace unskilled and semi-skilled labour. There are large international and interindustry differences in the diffusion of robots. Japan has the largest population (both in absolute numbers and in proportion to manufacturing employment) followed by Sweden and other European countries, like Italy and the Federal Republic of Germany, and the United States (in proportion to manufacturing employment).

Although the automobile industry is the major user of industrial robots in the Organization for Economic Co-operation and Development (OECD) countries, robots are also used in a number of other branches. In Japan, for instance, the most intensive user of robots (though a small user in absolute terms) is the bicycle industry, followed by automobiles, plastics, metal-processing machinery and electrical machinery). In the United States, in addition to automobiles (by far the largest user industry), electronics, foundries,

and non-metal light manufacturing are the largest user branches of robots.

Given the fact that robots are mainly an unskilled-labour saving technology, the diffusion of robots in the developing countries is still very limited. According to ECE, about 4,000 robots were installed in 1986 outside Asia (including Japan), North America, western and eastern Europe (including USSR). Presumably a number of them are in developing countries.

It is known that more than 300 robots were installed in Singapore in 1985 (Edquist & Jacobsson, 1988). In the Republic of Korea, Yugoslavia, India, Brazil, Argentina and Mexico, process robots are already being used in some factories and for educational purposes. Subsidiaries of transnational corporations (TNCs) producing motor cars both for export and the domestic market are already using robots in their factories in developing countries and robots are also being applied in the production of consumer goods (like TV sets and refrigerators).

A proportion of the robots used in developing countries are locally made and, at least in Brazil, the indigenous production is explicitly encouraged by the Government (as is the case with CNC units).

Further information on robots diffusion is available in studies made by OECD (1983), ECE (1985, 1988), Flamm (1986), Camagni (1988), Taulle (1987), and Edquist & Jacobsson (1988).

4. Flexible manufacturing systems

No agreed definition is available on FMS. While Bessant (1985) considers that FMS is "an approach to a particular set of manufacturing problems rather than any single technological configuration," both Edquist and Jacobsson (1988) and the ECE (1986) have attempted to define it.

According to ECE (1986, p.13) a FMS "an integrated computer-controlled complex of NCMTs, automated material and tool-handling devices and automated measuring and testing equipment that, with a minimum of manual intervention and short change-over time, can process any product belonging to certain specified families of products within its stated capability and to a predetermined schedule."

Several types of systems are defined. Flexible manufacturing unit (FMU) (usually one machine system), flexible manufacturing cell (FMC) (two or more machines) and FMS (two or more FMCs).

system), flexible manufacturing cell (FMC) (two or more machines) and FMS (two or more FMCs).

According to ECE, there were around 350 FMS installed in the world in 1984-85. In a study made in Italy about the diffusion of FMSs in six industrialized countries, it is stated that there were 182 at the end of 1984 and 250 at the end of 1986 (Gros Pietro 1987). Eighty-six were installed in Japan and 66 in the United States. The largest growth occurred in the United Kingdom (from 16 to 36) and in Italy there were 17 FMCs at the end of 1986.

In a study of the distribution of 129 FMSs by user industries, it was found that more than half were located in the non-electrical machinery sector and more than one third in the transportation equipment industry (Edquist & Jacobsson, 1988).

It is clear that FMSs are in the early stage of their diffusion and further technological development and cost reductions are needed for a wider diffusion. FMCs hardly exist in developing countries, although in the Republic of Korea there are a few. However, it is possible that some FMCs or FMSs are already being used.

Further information is provided in ECE (1986), Gros Pietro (1987), Camagni (1988), Edquist & Jacobsson (1988).

B. The diffusion and production of industrial automation technologies in developing countries: issues for the 1990s

From the brief review made above and the available literature, it is possible to reach some preliminary conclusions and suggest a number of issues that deserve close attention:

1. A number of new industrial automation technologies (e.g. CNCMTs, CAD systems, process robots) are already commercially available at reduced prices and with an increasing reliability, while other technologies (e.g. FMS) are still in the development stage and are expensive and not very reliable.
2. Technological progress in this field is very quick, making possible new developments like assembly robots or CAD systems for personal computers that will facilitate further diffusion of the technologies. However, the process of integration of the several industrial automation technologies is not without major problems and, therefore, predictions about commercial applications of these systems have to be carefully evaluated.

3. Despite the technological maturity, reduced prices and increasing reliability of these technologies, the process of diffusion, though very significant in the last ten years or so:

- (a) Is not as rapid as originally expected;
- (b) Is very uneven at country, industry and user firm level;
- (c) Has been implemented with a varied degree of success.

These features of the diffusion process are mostly explained by differences in country and firm experiences, though the uneven maturity of the technology in question also plays a role.

However, when successfully implemented, industrial automation technologies have proved to be an extremely powerful instrument to increase labour, and in some cases capital productivity. Moreover, they are useful in adapting the manufacturing assets and the product mix of the firms to the changing circumstances of the environment in which business is conducted, as well as in increasing the international competitiveness of the industry and firm in question.

4. The successful implementation of industrial automation technologies requires not only the incorporation of the relevant technological hardware and software. It also, and fundamentally, requires the development of an "industrial automation culture" through a number of organizational changes at the plant level to rationalize the production process and the relationship with suppliers and clients. Moreover, training of the relevant blue-collar and white-collar personnel to take advantage of the new technologies, adequate maintenance and repair skills and an expected market for the products to be produced with these technologies, allowing a relatively quick amortization of the investment in question, should be carefully planned.

If the introduction of industrial automation technologies is not done as part of a process of restructuring of the production management of the firm, the technology as such will not lead to any significant increase in labour productivity. When introduced as an integral part of a process of serious plant reorganization and industrial restructuring, however, industrial automation technologies can be a powerful tool to facilitate the reorganization process and increase the production efficiency at the task, shop, plant and industry levels.

5. Despite the reduced prices of industrial automation technologies, the adoption of these technologies is normally an expensive investment (when compared with conventional machines and or labour costs). Furthermore, these technologies require considerable repair and maintenance skills that are not easily available, especially in developing countries. Therefore, it is more likely that big firms with adequate financial resources will be the early adopters of these technologies. However, small firms with an adequate market for their product (e.g. subcontractors) are also likely adopters.

It is true that one of the great advantages of flexible automation is that it makes the production of small batches in discrete manufacturing as economic as was the production of such batches with conventional machines. It is also true that user firms need to have a substantial aggregate volume of production to be able to amortize the higher investment.

6. Although industrial automation technologies are adopted for many reasons, such as reduced lead time, quality consistency of the product, greater possibilities of product variety, and better management control of the production process, there is no doubt that cost reduction through labour saving is an important consideration for adopting these technologies. In the case of developing countries with low wages for skilled and/or unskilled personnel, it is extremely important to examine the extent to which reasons other than reduction in labour costs per unit of output can have a greater influence in the adoption process of these technologies.

On the other hand, the impact on the skill structure is an important variable to be taken into account. In countries with skilled labour shortages (of machinists, design and draughting technicians), the introduction of, for example, CNCMTs and CAD systems may be used for leap-frogging in the field of machining and especially of designing (Edquist & Jacobsson, 1988).

7. Given the rapid diffusion of some industrial automation technologies and the importance of having a local supply of these technologies to facilitate after-sales service and hence reduce repair and maintenance skills, the entry into the production of these technologies is quite important for countries undergoing a substantial development of the engineering industries if they wish to participate in the most dynamic segments of the industry and remain competitive. However,

despite the availability of technology sources and cheap electronic components, the barriers to entry into the production of the most mature and diffused industrial automation technologies are significant, leading to higher production costs and less reliable equipment in the case of indigenously produced equipment and hence hinder the diffusion process itself. To overcome such entry barriers, not only well-trained personnel and adequate design, production and marketing skills are needed, but a careful analysis of the degree of domestic integration of mechanical and electronic hardware and of the software must be made, as well as a determination of the minimum volume of production in competitive products required to be supplied to the domestic and, eventually, to export markets.

Thus, the impact of industrial automation technologies in the capital goods producing industries of developing countries is a very important issue that should be carefully considered.

The advances already made by developing countries in manufacturing engineering products will become more fragile and will not be sustainable in the long run. At the same time, the entry into the production of more complex capital goods will become more difficult unless these industrial automation technologies are applied. Hence, to remain outside this crucial technological development will only contribute to a further marginalization of developing countries from the key manufacturing activities.

From the typology of developing countries worked out by UNIDO (1985), it appears that this is a crucial issue for near forty developing countries having a very large and medium-to-large capacity for capital goods production (group A and B countries). For the remaining developing countries (group C) that hardly produce any capital goods, the entry into capital goods production may be even more difficult, though in some cases the skill formation process is less time-consuming.

The advantages of developing countries in the production of capital goods based on low wages for skilled and semiskilled labor can easily be eroded by the introduction of flexible automation technologies in the industrialized countries.

While it is true that industrial automation technologies do save labour and hence may have a negative impact on the employment of current engineering production, it is also true that in many cases such production will remain competitive and thus viable in the long run

only if these technologies are successfully implemented. On the other hand, and taking into account the skilled-labour-intensive nature of engineering production, skilled labour released from production of the engineering goods most affected by the technologies in question may eventually be employed to foster the production of other capital goods.

The less rapid diffusion of these technologies than originally expected should not lead to the conclusion that the impact is slowing down. On the contrary, this less rapid diffusion is an opportunity for developing countries to remain competitive in the production of engineering products and to benefit as soon as possible from the introduction of these technologies.

Despite the uneven diffusion process of these technologies in the engineering industries of industrialized countries, there is no doubt that their application in the manufacturing process of many capital goods is imperative if the manufacturer is to remain competitive in this segment of the world economy. It is a fact that a growing number of firms in developing countries are beginning to acknowledge and trying to act according to the new circumstances. However, relatively little is known about the diffusion process of these new technologies in developing countries other than the NICs.

It is unknown, for example, who the main users are, the reasons for the adoption, the factors accounting for the successful and unsuccessful incorporation of these technologies, the conditions and issues related to entry into production of these technologies, and the consequences of indigenous production for the diffusion process.

Only careful consideration of the factors affecting the diffusion and the eventual production processes of these new technologies will permit a diagnosis of the problems faced by several developing countries producing capital goods, at different levels of development. On that basis it will be possible to formulate policy recommendations to deal with industrial automation technologies and lead to UNIDO support programmes in the form of advice and technical assistance.

II. OUTLINE FOR A PROGRAMME ON INDUSTRIAL AUTOMATION OF THE CAPITAL GOODS INDUSTRY

The main objective of a programme on industrial automation should be to foster the development and competitiveness of the capital goods producing industries through an adequate and programmed introduction of new technologies in the engineering branches and an efficient entry into the development and production of these automation technologies.

UNIDO can assist developing countries in reaching this objective through the development and execution of technical assistance programmes tailor-made to overcome the problems prevailing in different countries.

In-depth knowledge of the different situations prevailing in developing countries regarding the diffusion and production of these technologies is needed in order to be able to formulate policies aimed at creating the domestic capabilities in the form of skilled resources and managerial capabilities on the basis of which an industrial automation culture may flourish.

The above-mentioned objective could be operationalized through a UNIDO support programme, which should be based on, among others things, the following activities:

1. Field analysis should be undertaken in the form of several country case studies aimed at shedding light on the factors accounting for the diffusion and eventual production of industrial automation technologies in a number of developing countries.

To have a good selection of relevant experiences, twelve countries should be selected within groups A and B (UNIDO, 1985).

2. On the basis of the findings of these country case studies, a typology should be prepared in which an attempt should be made to find certain common features and policy issues about the introduction, implementation and eventual production of industrial automation technologies. These common features should take into account the peculiarities of the various developing countries in terms of their recent macro-economic and industrial development, particularly in the domestic production and exports of engineering goods; their industrial, trade and technology policies framework; the employment and skill formation experiences; the various successful and unsuccessful experiences at the enterprise and industry levels regarding the adoption and

production of the technologies under study, paying special attention to the skills involved and managerial behaviour; the impact of the adoption of these technologies upon the competitiveness of capital goods production, etc.

3. On the basis of the country case studies and the above-mentioned typology, specific areas should be suggested on which developing countries should formulate concrete policies to facilitate the adoption and production of industrial automation technologies in the context of fostering the development of the capital goods producing industries and the role that UNIDO should play in this connection. These policies should take into account the peculiarities of each country situation and give appropriate attention to the production and managerial skills required for successfully implementing industrial automation technologies.
4. A capacity should be set up in UNIDO for supervising the above-mentioned studies and for providing technical assistance and specialized professional services to developing countries interested in adopting and producing industrial automation technologies and to enterprises that decide to incorporate these technologies. In this way, UNIDO should assist developing countries in this field through specific knowledge of the requirements for successfully adopting these technologies with particular emphasis on implications for management skills, training of human resources and know-how requirements.
5. A capacity should be set up within UNIDO to monitor the techno-economic developments in this field, both in industrialized and developing countries, and the experiences at the country and enterprise levels in the diffusion and production of industrial automation technologies.

A. Methodology to undertake a programme on industrial automation

1. The technologies to be analyzed

From the above-described technologies, attention should be paid to CNCMTs, CAD systems and industrial robots and eventually to PLCs, within process control equipment. The different types of CNCMTs and CAD systems should receive priority.

It can be assumed that these technologies are mostly diffused independently of each other and that, at least at the beginning, they will replace conventional technologies (i.e. an NC lathe replacing a conventional lathe) or simply reduce the amount of

skilled labour (of machinists, designers, welders) needed to produce an engineering item.

Unless surveys of the diffusion of these technologies are already available, a lot of work is involved in obtaining data related to the number of units installed, their unit value (c.i.f and included tariffs and other delivery expenses) and the country of origin. Sometimes, information on imported items can be obtained in trade statistics if the required technology is shown separately (for example, NC lathes are compiled as a separate category within lathes). This information can be supplemented by export figures from the supplying industrialized countries.

Data from trade statistics should be supplemented by information to be provided by commercial distributors of the imported equipment. These distributors can also provide the names and activities of their customers and details of the after-sales and training activities that they engage in.

It is very important to try to have not only the stock of the technologies installed in the country but also flow information. Such information for a number of years will permit an assessment of the time dimension of the phenomena under study.

2. Developing countries to be chosen (typology)

From the studies and activities of UNIDO and of other agencies and experts in the capital goods sector, the countries belonging to group A (Republic of Korea, Singapore, India, China, Argentina, Brazil and Mexico) are not only the countries with a fairly well-developed capital goods sector but also countries where the technologies under study are being diffused and, in some cases, locally produced.

Very relevant field work can be undertaken in these seven countries, taking into account the already available studies and information for a deeper understanding of the issues involved in both the diffusion and production of these technologies. The most relevant experience in Asia is that of the Republic of Korea. However, given the importance of its capital goods sector and its current technological transformation, China should receive priority.

In Latin America, Brazil is the most relevant experience to be studied, especially taking into account the amount of local production of the technologies under study. Argentina is also an interesting case to be further analysed. Despite the poor economic performance, the trade agreement with Brazil has

revitalized some segments of the machinery industry, including the production of CNCMTs, and the trade and co-operation agreement with Italy has facilitated imports of these technologies and the setting up of joint ventures between Italian and Argentine firms to manufacture CNCMTs. Taking into account what is already known and the importance of the issue under consideration, it would be advisable to concentrate efforts within group A countries in China, Argentina and Brazil. In these three countries the studies should pay attention to both the diffusion and the production processes of these technologies.

From the studies made by UNIDO in the capital goods sector, in addition to group A countries, the thirty countries in group B were considered to have a medium market, medium-to-large technological capacity and some development of the capital goods sector (UNIDO, 1985).

The most relevant developing countries with potential for industrial automation would be those in which the economy has performed rather well, investment ratios have been significant (hence, imports and local production of capital goods have gained momentum) and exports of capital goods have not only increased their importance in production but also been increasingly including more technically sophisticated products. The increase in local labour costs or the difficulties in finding skilled labour would be another factor encouraging the use of automation technologies. However, industrial automation also has a potential for adoption in countries with a poor recent economic performance. In cases where industrial restructuring schemes are taking place due, for example, to import liberalization policies, domestic firms may need to adopt automated equipment to be able to face import competition.

In the Asian region, countries like Thailand, Malaysia, Philippines, Indonesia and Pakistan are priority cases to be analyzed within group B countries.

An additional consideration for the inclusion of the member countries of the Association of South-East Asian Nations (ASEAN), is the growing importance of Japanese direct foreign investment in these countries since the yen revaluation. Although the reduction in labour costs is an important motivation for Japanese direct investment in some ASEAN countries, it is also possible that some sort of horizontal division of labour has been established among the parent companies and subsidiaries located in developing countries by which intra-industry trade will be developed and exports not only to third countries but to Japan will gain importance.

In this scheme it is likely that some of these production facilities have to produce components at quality levels that require automation technologies in some stages of the production process (e.g. machining operations) to meet the requirements of the joint production. Given the experience of the Japanese companies in the technologies under study, it is not unlikely that Japanese direct investment could become a vehicle for diffusing industrial automation to developing countries. This question, however, should be verified in the field work.

Within group B countries in Latin America, it would be advisable to concentrate efforts in Cuba, Colombia, Peru and Venezuela. The list of African countries might include Algeria, Morocco, Nigeria, Tunisia, Kenya and Zimbabwe.

While in the studies on Argentina, Brazil and China both diffusion and indigenous production trends and modalities will be studied, in the remaining developing countries priority should be given to the diffusion of imported flexible automation technologies, though some local production may also take place. The studies on group B countries will fill an important gap in the available literature on the subject and will permit an assessment of the possibilities of these countries to foster indigenous production of more technologically advanced engineering goods.

From the eighteen developing countries (six in Asia, six in Africa and six in Latin America) mentioned above, a list of at least twelve should finally be agreed upon as the subject of country case studies.

(3) Industries and user firms to be selected

From the studies already made in industrialized and developing countries, it is known that the industrial automation technologies are diffused mainly in the engineering industry or capital goods sector broadly defined (ISIC 38) and, more specifically, in non-electrical machinery, electrical machinery and transport equipment.

The priority subsectors within engineering production where the user firms should be selected are as follows:

1. Motor car production and spare parts and accessories;
2. Agriculture machinery, including tractors;
3. Cutting tools, pumps, valves and compressors;
4. Machine tools;

5. Special industrial machinery, especially construction machinery, food-processing machinery, textile machinery, clothing machinery, leather machinery, printing machinery, etc.;
6. Heavy electrical equipment;
7. Oil industry equipment;
8. Shipbuilding;
9. Railway equipment;
10. Aircraft and parts;
11. Electronic components.

In the countries with local production of the technologies under study the main producers (generally also users of the technologies) should be included in the sample firms to be surveyed.

If possible, the same subsectors should be chosen in different countries, in order to facilitate intercountry comparisons. If the same firm has affiliates or has transferred its technology to enterprises located in other countries to be included in the field work, both companies should be included.

Within the chosen subsectors, user firms to be studied should include as far as possible large-, medium- and small-size enterprises, both nationally and foreign-owned, that have incorporated and have substantial experience with one or more of the technologies under study. Subcontracting firms should also be included. For comparison purposes, when a specific firm is selected in a subsector, it would also be very useful to interview competitors that have not adopted the technology under study to try to assess the advantages and disadvantages gained by the adopting firms.

It is advisable to concentrate the study efforts within a few engineering branches and to have more than one firm in each branch, in order to be able to learn the specific situation of the subsector under consideration.

The selection process of the firms to be surveyed is not easy. It is rather advisable to have a longer list of firms and send a postal questionnaire with a few data and then to choose a reduced number of firms as the object of a thorough survey that should include detailed visits to the plants for interviewing the relevant managers.

Distributors of imported equipment, local producers (if they are available) and industry experts should be used to select the sample. The sample cannot be a

random one but efforts should be made to include a good representation of the country situation.

B. Structure of the country case studies

1. Macro-economic aspects

(a) Recent macro-economic performance

Information on the growth rate of the economy and of the manufacturing sector, the share of fixed investment (and especially of machinery and equipment) and of public investment in GDP, on unemployment, the inflation rate, the real rate of interest, the real rate of exchange evolution, exports and imports, external debt services, the balance of payment situation, etc. should be given in order to have an idea of the macro-economic environment of the country being studied. Special attention should be paid to fixed investment trends in the economy and the likely prospects for productive investment in the years to come. The availability of domestic and external credits (including subsidies like debt equity swaps or other subsidies on interest rates or special conditions for acquiring equipment) for productive investment is an important variable to be looked at.

The current situation regarding the labour market is also a relevant question. Analysis should cover not only unemployment rates in the economy and in the manufacturing sector but also the evolution of real wages in the manufacturing sector and indicators of labour unrest.

(b) Recent industrial development, especially that of the capital goods producing industries

Information on the main structural features of the manufacturing sector and of the engineering branches (ISIC 38) should be given (gross output, value added, exports, total employment and, if available, employment by main categories, labour productivity growth, size distribution of establishments).

The evolution of wages and salaries paid in the engineering branches should be given and, if possible, the relationship with productivity evolution. The degree of local integration of the production of engineering goods should be indicated as precisely as possible.

Product composition of exports of capital goods, their importance in production and the main destination of the exports should be given for at least three years.

Product composition of imports of capital goods, the share of imports in apparent consumption or total investment and the main origin of capital goods imports should be also given for at least three years.

The recent performance of the manufacturing sector and of the capital goods producing industries should be analyzed, not only in terms of their growth but also of their ability to meet investment requirements of goods of different levels of technological complexity. The physical and technological investments made by capital goods producers should be especially taken into account and the size and importance of technical departments in these firms should be pointed out.

Information on the degree of participation of subsidiaries of transnational corporations in the manufacturing sector and in the capital goods producing industries should be given, as well as indications of the branches in which local firms are predominant.

While for the manufacturing sector and the capital goods branches the above data are needed in order to have a proper understanding of the context, in which the case study is made, within the capital goods sector attention should be focused on the branches where the surveyed firms are included for studying the adoption of new technologies. The focus of the analysis in these specific branches should be on the competitiveness of locally made products and the factors explaining such competitiveness. Not only wages of unskilled and skilled personnel are key variables to be studied but also the prices of important inputs (steel, foundry, electrical components, etc.).

A relevant consideration in the analysis of capital goods production is the type of production process that prevails (i.e. the size of the batches) and the degree of product diversification of the capital producers.

(c) *The policy framework*

In addition to the macro-economic framework in which industry operates, it is important to point out specific areas that may influence the business environment in which firms to be surveyed have been operating.

If there are specific industry regulations promoting the production of the goods in question through fiscal and/or financial incentives, tariff and non-tariff protective measures, etc., they have to be carefully considered.

It may also be the case that, due to restructuring policies undertaken by the Government, the capital goods branches in which the surveyed firms operate are strongly affected by changes in the policy environment.

Even if no specific industry regulations or restructuring schemes are in force for the capital goods producing industries or for the branches using the machinery made by such industries, general regulations governing the following should be taken into account:

1. Procurement of capital goods by public enterprises;
2. Tariff and non-tariff protection to imported equipment and/or imported parts and components, including tariff exceptions to imports of capital goods when they are made by public enterprises or by firms included in industrial promotion schemes;
3. The degree of local integration of domestic production of machinery and equipment;
4. Credit facilities to purchase locally made equipment;
5. Fiscal facilities for undertaking research and development activities;
6. Direct foreign investment policies, including those of export processing zones;
7. Relevant imports of intangible technology.

(d) *Training and educational situation*

The availability and quality of skilled people needed to operate conventional and computerized equipment is a key aspect to be considered. Information on the curriculum of vocational schools, technical schools and universities for the training of adequate personnel to deal with the operation, programme and management of these techniques should be gathered. Programmers, mechanical and electronic technicians for repair and maintenance and other skilled personnel are going to be needed in any policy to foster the introduction of automation technologies. Although learning on the job is extremely important, there is no doubt that the educational system should play a key role in this area. Scientists, engineers and management consultants are also required for any systematic effort in this field and their training and retraining is an area of utmost importance. Thus, it is very important to obtain information on the country situation in this respect.

2. The diffusion process of industrial automation technologies at the enterprise level

(a) General information on the enterprise

The following general information on the enterprise should be taken into account:

1. Year of foundation of the firm as a manufacturing enterprise;
2. Origins of the firm (as a distributor of imported equipment, as a repair and maintenance shop, etc.);
3. Juridical situation (family owned, joint stock company);
4. If it is a subsidiary who is the parent company? If it is a joint venture who is the foreign partner? If it is a licensee who is the licensor, what are the products made under licence and what features does the agreement have (know-how, patents, trademark, export restrictions, tied inputs, royalty payments, duration, etc.);
5. Total employment and employment by main area (administration, sales, production, technical department, research and development) and by skill (unskilled workers, skilled workers, supervisors technicians, engineers, programmers, etc.);
6. Total production and/or sales for domestic market and exports; main orders; breakdown by main product category;
7. Market share in the domestic markets for the main product categories;
8. Value (at insurance cost if possible) of the fixed assets of the firm, divided in buildings and machinery and equipment;
9. Brief description (hardware and software), origin, year and value of acquisition of the existing industrial automation technologies installed in the enterprise; for comparative purposes, an indication of the number of conventional machine tools that exist in the enterprise and of the computers used for different purposes;
10. Specific products for which automation technologies are used; size of the batch production in which the products are made; frequency of repeat runs;
11. The extent to which the automation technologies are linked to the other production processes in the factories; islands of automation;

12. Main customers of the enterprise products; if it is a subcontractor, the name of the contractor and type of arrangement and its duration;
13. Main competitors of the enterprise; type of competition prevailing in this specific market (price, quality, after-sales service); the extent to which imported products play an important role in the competition process;
14. Export performance and experience of the firm; products with better export performance; advantages of the products in terms of price, quality, technology embodied in the export market; main customers abroad; competitor firms in the export markets.

(b) Reasons for adopting the technologies

The reasons for adopting the technologies should be considered. These may include the following:

1. The technology was adopted as part of a reorganization or rationalization process carried out by the firm or it was an isolated decision;
2. The main specific reasons for adopting each technology:
 - (a) Reduction in labour costs (of which machinists, draughtsmen, designers, welders, painters, etc.);
 - (b) Lack of skilled personnel;
 - (c) Quality and technical features (e.g. complexity, precision standards) of the product or component that the technology is used to produce;
 - (d) Reduction in machining and designing times;
 - (e) Changing and upgrading of the product mix and greater possibilities of product variety (economies of scope);
 - (f) Reduced lead time;
 - (g) Dangerous or unpleasant tasks (for robots);
 - (h) Better management control of the production process;
 - (i) To be aware of the technology for long-term considerations
 - (j) Other reasons (specify).
3. In addition to the existing equipment, plans to introduce additional technologies; which technologies and purposes;
4. Number of workers or technicians displaced by the introduction of the technologies; reasons (if any) and the extent of labour displacement due

specifically to the application of the technology; if the technology had not been introduced, would it have been possible to keep the workers involved in the production process anyway?;

5. If workers were not displaced but retrained, an indication of how the retraining programme was implemented and by whom; salary modifications due to the lower skills needed for operating the equipment in question;
6. New skills incorporated to deal with the new technologies; previous training and the actual training of the new skills; who took care of the training and for how long; shortages of skilled people for the new technology and which skills;
7. Wages for the new skills compared with those of the previous employees operating conventional equipment;
8. Person in charge of programming the equipment; package software used; software adaptation, modification and improvement; acquisition of additional software packages to deal with the several applications of the technology; handling and management of software needs and updating;
9. Experience regarding the repair and maintenance of the equipment (skilled people in the firm, by specialized firms, by the vendor); actual costs of repair and maintenance and comparison with the actual costs of repair and maintenance of conventional equipment; advantages or disadvantages regarding repair and maintenance when the equipment is made by a local producer.

(c) Assessment of the impact of the introduced technology

Although it is very difficult to isolate the results of one specific factor (the introduction of the technologies under study) among various factors accounting for the industrial and commercial performance of an enterprise, an attempt should be made to shed light on this crucial issue on the basis of the findings of the country case study.

When these technologies are successfully incorporated into the production process of the user enterprise, the growing labour productivity and the ability to make new products of good quality should be reflected in the performance of the firm in the domestic and export market. In other words, the adopting firm will gain price and product competitiveness on the basis of genuine technological and organizational changes and will be able to respond in a flexible and quick manner to market requirements.

However, although the technologies under study are especially suited for producing in an economic manner a variety of goods made in small batches, the demand for all the firm's products has to be sufficient to pay off the costs of the investment. Hence the question of the market for the products made becomes a crucial one that cannot be underestimated. It is for these reasons that the peculiarities of the country macro-economic and manufacturing situation have to be specifically taken into account in assessing the impact of these technologies, including:

1. Preparatory work done for deciding the adoption of the technology; feasibility studies made before acquiring the technology; main conclusions;
2. How the specific equipment and the software were chosen and by whom, once the decision to acquire the technology in question was made;
3. After-sales service offered by the vendor;
4. Role played by customers or sub-contractors in the decision to introduce the relevant technology in a production process;
5. If a CNCMT was chosen instead of a conventional machine tool, concrete examples of the investment calculations assuming one- and two-shift operation, the actually paid labour costs and the costs of both machines and other fixed investment.

Examples for investment in other automation technologies should also be given if possible (e.g. the pay-off for introducing robots of CAD systems)

In cases where these calculations were not actually made, it would be interesting to learn why.

(c) Actual experience with the technologies adopted

The actual experience with the adopted technologies should be examined. This may include the following:

1. The organizational changes made in the firm to take advantage of the application of the technology regarding:
 - (a) Factory layout;
 - (b) Methods and organization office;
 - (c) Quality control at shop and factory level;
 - (d) Management of stocks of spare parts, components and work in progress;
 - (e) Relations with subcontractors;
 - (f) Product planning;

- (g) Design department;
 - (h) Other activities (specify):
2. Any specific computerized system used in the activities mentioned above; external management consultants or specialized personnel used to introduce the required organizational changes;
 3. Ex-post productivity gains achieved by the specific application of the technologies under study; time needed to achieve these gains;
 4. The specific modification made in the software or hardware of the equipment and/or a beginning of a process for integrating the various technologies, with a view to achieving the productivity gains;
 5. Gains other than the reasons mentioned above obtained by the ex-post application of the technology; ways in which gains were the result of integrating the various technologies.

One way to assess the net effect-of the introduction of these technologies in the same country framework is to compare in the same subsector competing firms successfully adopting the technology with firms that have not made such a decision and to try to examine their comparative performance in the domestic or export markets.

In addition to assessing the impact of the introduction of these technologies in successful cases and the factors accounting for such a success, it is extremely important to indicate the main factors accounting for the lack of success in the introduction of these technologies.

The findings of the survey will be very relevant in pointing out the main areas at the enterprise and at industry levels on which specialized technical assistance should be given to facilitate the adoption process of these technologies and the policy measures best suited to promote an efficient adoption of automation technologies in the engineering industries of the countries studied.

Finally, on the basis of the findings of the case study and information from distributors, an attempt to forecast the future diffusion patterns of these technologies in the country can eventually be made. If the market for these technologies seems promising, there will certainly be room for indigenous production, an issue that should also be investigated.

3. Issues related to the production process to be investigated in the field

In developing countries like China, Argentina and

Brazil (not to mention the Republic of Korea, Singapore and India), some of these technologies are already made by local companies, under licence from firms based in industrialized countries by affiliates of foreign firms through their own design efforts.

Jacobsson (1986), Fransman (1987), Chudnovsky (1985, 1988) have studied some of the issues involved in the production of CNCMTs, including the production of the CNC unit. No studies on the development and production of robots and CAD systems are available, though in Brazil at least there is already some production encouraged by specific government policies. The picture is, however, changing so quickly that further studies are needed to have a good assessment of the situation, especially in China, Brazil and Argentina, where production has gained momentum, at least in the case of CNCMTs. In other developing countries to be studied, it is very likely that the issue of local production may arise as well.

To encourage local production of these technologies will certainly mean higher prices (higher than those of imported equipment), at least in the short and medium run, and hence it may hinder the process of diffusion of these technologies among user industries. While in the short and medium run a conflict between indigenous production and local diffusion may arise, in the long run, when local production becomes competitive, it will certainly facilitate a further diffusion. However, even in the short run there are certain benefits that can compensate the higher prices to be paid for locally made equipment. The most important benefits that user firms may derive from indigenous production of the relevant technologies are:

1. Better after sales services;
2. Better and quicker assistance for repair and maintenance of the installed equipment;
3. Better facilities for personnel training;
4. Adaptation of the hardware and software to the specific country situation.

Against these benefits (which should be verified at the country level), the main costs may be higher prices, less sophisticated equipment (though this could sometimes be an advantage) and difficult access to the latest technology.

These benefits and costs of indigenously made equipment versus those of imported equipment should be discussed with the user firms interviewed in the diffusion study, when there is of course local production.

Regarding the study to be made about the entry into the development and production of industrial automation technologies in developing countries, all the questions and issues referred to above apply to the producers of the equipment in question because it is very likely that these firms themselves have already incorporated these technologies. In fact it would be surprising to find a local producer of these technologies that has not used at least one of them for designing or producing them.

The specific issues to be further investigated among firms producing in developing countries are as follows:

1. How the technology is acquired and updated; if a licence agreement is in force, it would be important to learn the details of the agreement (whether basic and detailed design is included, whether hardware and software is included, etc.), how the licensor was chosen and what was the actual experience in terms of technology transfer of the mechanical and electronic know-how. The same questions apply in cases of joint ventures or subsidiaries obtaining the technology from the foreign partner or foreign owner.
2. The role played by the Government in the negotiation of the technology to be incorporated.
3. If the technology was developed by the firm itself, the human and financial resources involved; main sources of inspiration (visits to fairs, requirements of clients, imitation of imported models); months of design activity of senior and junior personnel required;
4. Source of hardware and software if not the licensor or foreign partner;
5. In the case of CNCMTs, units used and their source; an indication of whether suppliers of the electronic units have local sales and training offices.
6. If there is local production of the electronic items, the details of how these technologies were obtained.
7. Degree of local integration for the mechanical and electronic parts; evolution of production process over time; government regulations regarding local integration;
8. Extent to which domestic suppliers for parts and components exist in the country or have been developed to reach higher levels of local integration; the role played by the producing firm in this regard.
9. In addition to the design skills, how the manufacturing skills for producing the relevant technology were acquired and developed within the firm;
10. Minimum annual level of production for both the mechanical side and the electronic unit to reach competitive prices for the final product; how far from the minimum level the firm in question started the production process and where it is now;
11. In addition to raising the level of production, other ways in which the learning process in the producing firm can be measured and assessed;
12. Extent to which the firm in question is subsidizing with profits made in other lines of production the entry into production of the relevant automation technologies; an indication of whether there is a government subsidy for undertaking this production or whether if the acquisition of the locally made equipment receives a subsidy to facilitate the purchase.
13. Price evolution of the equipment made locally over time and relative to conventional equipment; how far the gap is vis-a-vis prices of imported equipment;
14. Specific experience exporting the locally made products; niche to be served by the firm; markets of export successes; main sources of competitive advantage in these products.

(c) Operational activities to implement the work programme

The implementation of the country case studies and of the consolidated report is not an easy task. It can be roughly estimated that each country case study will require at least six months to be completed and the consolidated report cannot be undertaken until all studies are done. The consolidated report will require nine months of work for a senior consultant with a lot of experience on the subject and ideally one that has already made one of the country case studies.

Once the countries to be studied and the consultants to undertake the case studies are chosen, it is very important to have a meeting of all the people involved in the project (including the consultant who will prepare the consolidated report if he or she is not already in charge of one of the country case studies, which is highly advisable), including the UNIDO officials, to discuss in detail all the methodological reasons for doing the country case studies and the survey of the enterprises.

The first meeting should be convened once all the consultants in charge of the studies have collected

preliminary information on the diffusion of technologies to be studied, have a tentative list of the firms to be interviewed, have made a pilot interview and have a concrete proposal on the firms to be surveyed.

In addition to discussing all the relevant methodological problems, it is important to decide in the meeting which are the subsectors finally chosen to allow further comparison.

A second meeting should be called out once the first drafts of the complete country case studies are ready and evaluated by the consultant. On the basis of his suggestions and those of the UNIDO officials working on the subject, the second meeting will address the tasks remaining to complete the case studies. At the same time, an exchange of views should take place on the policy issues found and on the successful and unsuccessful experiences at the country level.

The last meeting should be convened to discuss the first draft of the consolidated report and to receive suggestions from some of the consultants participating in the country case studies and from external experts on how to finalize the consolidated report.

The country case studies should be entrusted to an experienced consultant (senior industrial economist), assisted by a part-time engineer in the selection of firms and in conducting the interviews and by some junior staff collecting the data, in conducting the interviews and preparing the report.

III. UNIDO TECHNICAL CO-OPERATION ACTIVITIES IN INDUSTRIAL AUTOMATION

The work of UNIDO falls broadly under three categories:

1. Technical co-operation with Governments in developing countries (and through them with industry).
2. Studies, meetings and symposia in support of industrialization, for example studies of industry in a particular country or a particular sector such as machine tools and CAD/CAM.
3. Promotion of co-operation and investment in developing countries.

This section is concerned with the first and second of these activities with UNIDO technical assistance in the field of machine tools and CAD/CAM in particular.

Technical co-operation in support of industrialization involves the use of voluntary funds to assist a government, or through the government an industrial organization such as a manufacturer or industrial support-institution. The voluntary funds come from donor countries, largely by way of the United Nations Development Programme (UNDP), but increasing directly to UNIDO via the Industrial Development Fund. These funds enable UNIDO, with the government, to draw up projects that mobilize expertise, equipment and services such as training, to solve an identified industrial problem. The size of this part of UNIDO business is indicated by the total value of UNIDO technical assistance in 1990: \$130 million.

Assistance specific to machine tool design, development and manufacture, including applications and tooling, falls within the responsibility of the Engineering Industries Branch of the Department of Industrial Operations of UNIDO. The type of assistance is always determined by what the Government wants. Generally this reflects the level of development of the local machine tools industry. More advanced countries look to UNIDO for help in upgrading production and use of numerically-controlled (NC) and computerized numerically controlled (CNC) equipment, and in design and use of advanced tooling. Less advanced countries want to improve the capabilities in building conventional machinery, for example by increasing local content. The examples below illustrate UNIDO projects that help the whole industry by means of direct assistance to governments, by support of a national machine tool institution in the form of planning and feasibility studies. Other projects directly assist manufacturers with specific problems, or that focus on tool and die technology.

A. Direct assistance to governments

In China, UNIDO assistance is directed at developing and implementing programmes that inter alia will help the Government modernizing a number of machine tools manufacturing plants and foundry machinery industry.

In Nigeria UNIDO assisted the Government in the preparation of a detailed techno-economic study for the manufacture of conventional machine tools. Its outcome was positive and led to a decision to establish a machine tool manufacturing complex for conventional machine tools. However, UNIDO was not required to participate in its actual construction, which proceeded under technical co-operation among developing countries (TCDC) arrangement with India.

Under a bilateral collaboration agreement between the Government of Nigeria and one of the largest machine tool manufacturers in Asia, Hindustan Machine Tools International in India (HMTI), India is providing design and manufacturing know-how and training national experts. The Government of India is participating financially in an agreed production programme involving a multimillion-dollar investment in machinery.

B. Building up institutions

Hindustan Machine Tools International in India manufactures many different types of machine tools under license. Its management decided in the early 1970s that there was a requirement for research and development work, design and prototype manufacture to be carried out by an independent institute. Thus CMTI, the Central Machine Tool Institute was established and with it a co-operation with UNIDO that so far has lasted 15 years. During the Institute's establishment and implementation UNIDO assistance was furnished in areas such as applied metalcutting research, analysis of mechanical structures of machine tools, utilization of CNC machining techniques, and CNC training for users from industry. CMTI also introduced CAD/CAM techniques and their application in industry. Further assistance from UNIDO is now being discussed for introduction of CIM in CMTI.

Another institution-building project, for the Democratic People's of Korea, was successfully completed at the end of 1987. As a result the country's industry now offers third generation equipment featuring its own control system. Prior to the project, the Democratic People's Republic of Korea manufactured conventional machine tools such as various type of lathes, milling machines, radial drilling machines and grinding machines, at a rate of approximately 6,000 machines per annum. This capacity was traditionally a key export item and foreign exchange earner. With the introduction of NC and CNC machine tools the sale of conventional machinery dropped, however, and it became essential to develop a national capability to design and manufacture NC machine tools. To that end, UNIDO provided assistance to the Institute of Controlled Machines within the Academy of Science over a few year period. UNIDO supplied, installed and commissioned equipment valued at \$1.5 million, organized 250 w/m of fellowship training and provided 77 w/m of expert services. UNIDO trained the

national counterparts of the Institute at all levels, enabling it to transfer its acquired know-how to industry with a view to modernizing the local machine tool manufacturing programme.

Institutional-building of a different sort was carried out in Indonesia, where the machine tool industry is still in the infant stage. The machine tools produced (mainly by assembly) are of conventional type and useful for training and light machining repair purposes. P.T. Pindad in Bandung has licences for centre lathes and milling machines; P.T. IMPI, the other public enterprise situation at Cilegon, has a collaboration agreement with Mondiale of Belgium for manufacturing conventional lathes. The local manufacturing content of both of these manufacturers is only about 50 per cent. Imported components include lead screws, hardened and ground gears, main spindles, clutches and precision engineering parts. In addition to these two major machine tool manufacturers there are seven very small manufacturers producing small drilling machines and press brakes, some of which are somewhat inferior copies of simple machines.

It was in this context that Indonesia recently created the Machine Tool Association (ASIMPI). Together with UNIDO, it now intends to establish within existing premises an autonomous Machine Tool Design and Development Centre for the benefit of the Association. Its objective is to increase local manufacturing content, develop a local design and manufacturing capacity leading gradually to indigenous manufacture of more versatile machine tools. In this phase a number of national experts will be trained in trouble shooting, identification of machine tool user's problems and providing solutions.

Some institutional building is likely in China, where the Government is presently exploring the possibility of seeking UNIDO assistance aimed at building up the capability of the Beijing Numerical Control Technical Development Centre at the Beijing Machine Tools Research Institute to develop CNC systems that suit China's conditions.

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C. Direct assistance to enterprises

China is also seeking direct assistance to individual machine tool works wishing to build up their capabilities in modular design, development of a CNC control unit for machine tools, strengthening the foundry machine industry, use of independent manufacturing islands, NC turret design and technology. Substantial preparatory work with UNIDO involvement was carried out.

Assistance in the introduction of modern machining techniques through the development, manufacture and application of modern tools and dies is rendered by UNIDO through the establishment of appropriate institutions/or through existing institutions factories. Such assistance is being presently rendered on a large scale to the Engineering Design and Tool Centre in Ethiopia, and on smaller scale to a great number of countries.

Since the mid 1970s UNIDO has been assisting (via de Government of Trinidad and Tobago), the Metal Industries Company (MIC) to develop a local tool design and tool manufacturing capability. UNIDO provided sophisticated conventional tool-making machinery and related expertise to create a well-qualified local cadre of engineers and technicians within MIC. By means of extension services and training, this benefits local industry. More recently MIC recognized the need for boosting its capabilities for moving to a higher level of sophistication utilizing CAM and CNC techniques for tool design and manufacturing via UNIDO. MIC has acquired equipment, such as a CNC boring and milling machine (Maho MH 100 c/K), a CNC electro-erosion wire-cutting machine, a mini-computer with work stations. UNIDO will also provide the expertise and training to properly utilize and maintain this equipment.

In China, special assistance has been sought from UNIDO in the field of fine blanking technology in order to make better use of capital-intensive fine blanking presses already installed in a number of enterprises, which are underutilized and are currently producing inferior precision parts and components.

In other context, at the recommendation of the Latin American and Caribbean Group (GRULAC), UNIDO is undertaking a Regional Co-operation Programme for the Industrial Recovery of Latin America and the Caribbean. In the framework of this request, UNIDO has proposed to carry-out a special

regional programme for the capital goods industries, which should be oriented to promote the modernization of this sector.

The establishment of a Regional Programme on Industrial Automation of the Capital Goods Sector of Latin America will permit to the private sector counterparts to:

1. Set up a capacity in the countries to provide direct technical assistance and specialized professional services to enterprises which decide to introduce automation technologies, strategic management, and total quality control systems;
2. Provide decision-makers in enterprises at different levels of the public and private sector with the necessary information for a rational automation policy through:
 - (a) Knowledge of the technical requirements for upgrading the capital goods industry, to improve the use of installed capacity and increase productivity;
 - (b) Knowledge of the impact of industrial automation on specific branches of the capital goods industries with particular emphasis on the implications for training human resources, management skills and know-how requirements.

The objective of the Regional Programme will be to foster development of the capital goods industry in Latin American countries through an adequate and programmed introduction of industrial automation technologies, strategic management, and total quality control. This requires the formulation of sound strategies and policies to create the necessary domestic capacities in the form of human resources and managerial capabilities.

The Regional Programme will consist of one unit of administration and the following four sub-programmes:

1. Entrepreneurial advice;
2. Training;
3. Institutional support;
4. Studies and promotion of research and development.

Specific outputs at the regional and national levels will be obtained. The Regional Programme is oriented to the private sector organizations of the capital goods industry in Latin American countries.

D. Studies and reports

A study focussing on the technological requirements for the machine tools industry in developing countries was prepared for a meeting on production and use of machine tools in the engineering industry of developing countries of the Economic and Social Commission for Asia and the Pacific (ESCAP). This was jointly organized by UNIDO and the ESCAP UNIDO Division of Industry, Human Settlements and Technology, and held in Singapore in November 1986. That work, subsequently issued in the UNIDO *Sectoral Working Paper Series*, focussed on the technological requirements in developing countries for entry into the machine tools industry. It covered the criteria for selecting machine tools, the inputs, required, designs and standards, license deals, human resources, repair and maintenance, the economics of machine tools and a strategy for forming a machine tool company. It also elaborated the technological requirements and the possibilities for upgrading the existing machine tool industry in developing countries. For example, the feasibility of upgrading was found to depend on the basic configuration, the primary drive-speed selection, axes operation and accuracy and the economics involved. In addition to the enormous advantages, the study underlined the enormous difficulties facing developing countries in catching up in the field. Its recommendations included drawing up a market plan, establishing a Government-level working party representing finance, industry and education in a classic delta system of project management, making a skills audit relative to CNC machines and computer aids such as CAD/CAM, setting up a modular pilot scheme comprising several modern CNC machines and their associated computer-aided productive systems. Planned improvements should be implemented under a formal project management team. It was pointed out in the study that good project management was expensive but rarely as expensive as a failed project.

Recent UNIDO publication entitled *Planning and Programming the Introduction of CAD/CAM Systems - A Reference Guide for Developing Countries*, presents in a systematic way the factors that developing countries should consider when deciding to introduce industrial automation technologies in the production processes, mainly in the capital goods industry.

With the advent of the new technology associated with CAD/CAM, the performance of small and medium-size engineering industries in many developing countries has been remarkably enhanced since the early 1980s. In developing countries, small and medium-scale enterprises have become aware of their technological deficiencies in turning out competitive products with respect to product design, cost and delivery dates.

The UNIDO publication presents three main topics covering:

1. The technological aspects of CAD/CAM with a description of the most advanced computer-aided design and computer-aided manufacturing technologies explaining hardware, software and systems including work stations, displays, plotters, computers, data bases and networks;
2. Evaluation of available CAD/CAM systems through a detailed and clear explanation of how to compare systems and suppliers, the ramifications of purchasing turnkey systems, how to determine CAD/CAM needs and how to prepare a financial justification;
3. Management approach for implementation of CAD/CAM systems, with indications of the changes at organizational level, and applications in solid modelling, group technology, computer-aided process planning, artificial intelligence, and personal computers applications of CAD/CAM for the small metal-working industry.

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PART TWO

ECONOMIC AND POLICY-MAKING ASPECTS OF CIM -

PATTERNS AND MOTIVES FOR DIFFUSION

ECONOMIC ASPECTS OF FMS DIFFUSION IN THE WORLD

by I. TCHIJOV, International Institute for Applied Systems Analysis, Laxenburg, Austria

The flexible manufacturing system (FMS) is a key element of the CIM concept. It plays the main role in the production process, undertaking metalcutting, metalforming, joining, assembling and often quality control operations. Other CIM elements, like computer-aided design (CAD), computer-aided planning (CAP), computer-aided engineering (CAE), computer-aided logistics (CAL), etc. support FMS production processes and increase their efficiency, but not producing goods.

However, the efficiency of FMS, or its economic profitability, crucially depends on the use of these supplementary elements (FMS environment) and their compatibility with a system. Roughly speaking, an FMS could be economically beneficial if it is installed in an appropriate place (niche) at the appropriate time and is compatible with other computerized and conventional elements of its environment. Naturally, the system must be operated by personnel with adequate skills. All of these aspects will be analyzed in this paper, and in the context of an FMS diffusion study based on the World FMS Data Bank (Tchijov 89,1) (developed in IASA's CIM Project).

1. FMS DRIVING FORCES

When looking at the history of more than 100 years of industrial production development, one can clearly follow the dialectics of major production methods. At the first stage, the goal was to increase production volumes of quite limited numbers of goods (largely primary goods), dictated by the need to reduce the cost of one-off unit production.

The main solution to the problem was perceived as being through deepening the division of labor, where a worker of relatively narrow specialization could repeatedly carry out the simplest operations demanding low skills. Only the final operations – assembling, quality control, tuning, etc. – were the privilege of more highly skilled workers performing a variety of different and more complex operations. This trend was accompanied by standardization of goods, production unification, growth in the number of parts to be assembled, and an increase in the number of operations in final goods production.

Production was spread both in space and time. Manufacturing industries were turning from unit to serial production and from serial to mass production.

By the middle of this century, these tendencies of industrial production gave rise to numerous new factors, whose movements inevitably put an end to such developments. First, the demand structure changed. After primary needs had been satisfied at certain levels by the mass production of major goods, the differentiation process of demand for the variety of goods and improvements in their quality began. Structural changes in demand and fashion called for more frequent changes in the design of goods. Differentiation of goods production due to their quality and other specific features grew. "Product cycles are shortening dramatically. Car models, once in production for 12 years or more, are now being replaced every six years. Electronic gadgets no longer remain in production for three years, but three months" (Valery 87).

For example, Ford Motors produced one car model in 1915, three in 1953 and 13 in the mid-1970s. For these 13 models, five types of bodies and nine types of engines were produced simultaneously (Abernathy 78). Similarly, the number of variants of BMW cars increased by a factor of four over a five-year period (1982-87) (Reitzle 89).

The shorter life cycle of goods demands a higher cost of production lines re-equipment. This is true for stand-alone machines, but is much more important for fixed automation lines. The growing cost of model changes, combined with the statistically observed decline of the economic benefits of the change is known as "Abernathy's dilemma" (Abernathy 78). The introduction of FMS may help in reducing the cost of model changes, and allow clearer decisions on the problem of product innovation.

One can observe such a trend in the production of other consumer durable goods, and a similar tendency is discernible in the production of industrial equipment. Currently, 60-70% of all metalworking industries output in developed countries is of a small batch size, thus, a shift from "economy of scale" to "economy of scope" becomes unavoidable.

One of the factors which caused a rejection of the concept of mass production has been demand changes. These clarified the potential perspectives or advantages of flexible industrial production.

At the same time, within the production itself, new factors came into being, and brought to life a new style of industrial production. One of the factors came from the technological side. Unit cost growth took place due to the increasing needs for intermediate control when parts production is spread over space and time. As the number of parts in each car increased to 20-30 thousand and their processing was dispersed, the role of intermediate control and the cost of providing the necessary quality of the final product increased enormously.

The process of quality improvement as well as the creation of products satisfying new customer needs includes a fundamental internal conflict: "Every design engineer would like to achieve a functional superiority and therefore often complex product, but the production engineer ... wants to manufacture products from components which are not too numerous and complicated and which involve the simplest possible assembly processes" (Reitzle 89).

FMS facilitate smoothing these contradictions through so-called "redesign processes" (mutual iterative adaptation of product design and the technological process), but also through providing appropriate technological means for one-off production in the multistep procedure of creation and testing of new products. From the quality viewpoint FMS implementation leads to higher product quality standards and to a narrower quality spread.

Higher demands on product quality and technological sophistication, which require the precise following of technological process norms, as well as the need to reduce the control processes and inventory costs, are leading to the substitution of computer control for human control. But only flexible equipment can replace the flexibility and adaptability of human

beings. This means that quality factors create an additional possibility for flexible equipment with computer controls to further penetrate industrial production.

Finally, a third group of factors, which drives flexible computerized manufacturing, is in the socio-psychological sphere. The tendency to the division of labor, simplification of operations performed by a worker and the introduction of mass production, and conveyor systems, determined the pace of operations and led to a growth in the share of unskilled workers performing the simplified operations repeatedly and monotonously.

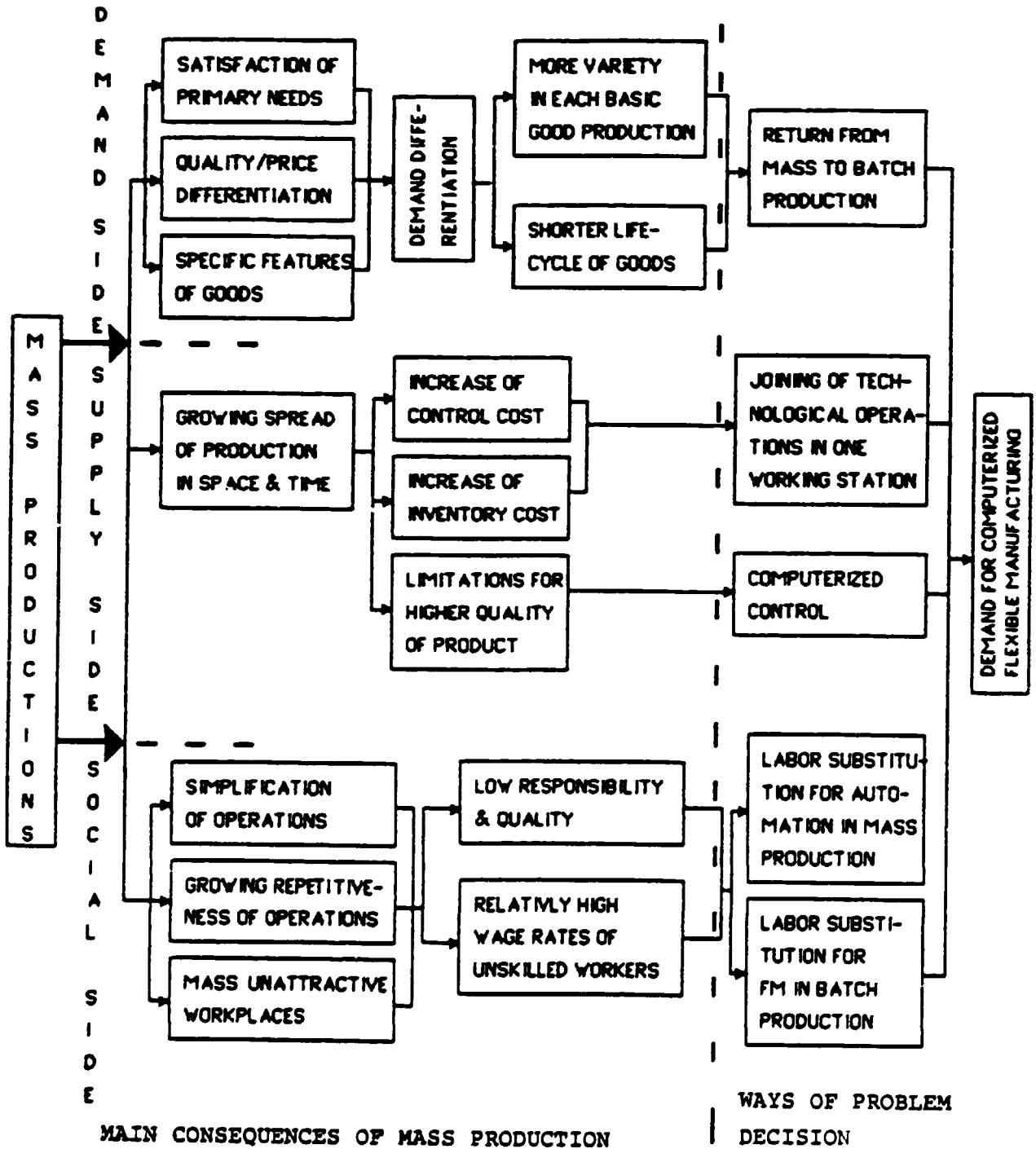
From the middle of the twentieth century, a tendency has emerged when the wages of employees engaged in these productions grew rapidly. A dichotomy came into view when unskilled (but unattractive) labor became similarly paid (sometimes, even higher) as complicated and skilled labor.

In an attempt to overcome these contradictions, in some cases human labor in monotonously repetitive and unattractive operations was replaced by automated tools. This took place first in mass or in large-batch production. However, in cases of small- and medium-size batches or, technologically sophisticated production, where decision or choice making is important, automated tools cannot replace the human being. Only flexible manufacturing can fill this role.

The skill demands in operating new technologies are very high, and personal responsibility increases owing to the extremely high cost of human error. According to Japanese data, 60% of all FMS failures are due to operators' errors, 25% to engineers' errors and only 15% to tool problems (Sata 85).

The interrelations of the driving forces generated in the process of replacement of mass by flexible production are shown in Figure 1.

Figure 1. Driving forces of computer integrated flexible manufacturing



2. FMS DIFFUSION

The assessment of FMS diffusion in world industry requires statistical support. That was why several generations of the World FMS Data Bank were developed within IIASA's CIM Project. The first version of the bank was based mainly on UN information (ICE 86) and (Darrow 86), and the first analysis of the FMS data bank was published in (Tchijov & Sheinin 89).

Later we were supplied with additional data from the collaboration network of the project. Many additional cases and figures were taken from scientific journals, books, occasional papers, etc. When the data had

been collected we asked national experts from IIASA's external collaborative network to check the data. We received many valuable comments and additional data from colleagues and we should like to express our appreciation for the support provided by V. Ganovsky, B. Haywood, H.-D. Haustein, R. Jaikumar, Z. Kozar, P. Lindberg, M.E. Merchant, J. Mieskonen, S. Mori, M. Ollus, V. Rakhmankulov, J. Ranta, G. Tondl and H.-J. Warnecke in the development of the FMS data bank.

As a result, the fourth version of the bank (Tchijov 89,1) contains 880 FMS installed in 29 countries (see Table 2) and described with 33 indicators (the most important of them are shown in Table 1).

Table 1

Number of cases with the main FMS indicators

Indicators	Version 4	Share in total, %
1. Technical complexity (TC)	784	89
2. Product variants (PV)	525	60
3. Batch size (BS)	259	29
4. Investments (INV)	314	36
5. Pay-back time (PBT)	98	11
6. Lead time reduction (L.T.R)	107	12
7. Set-up time reduction (SUT)	45	5
8. In-process time reduction (IPT)	90	10
9. Machining time reduction (MT)	46	5
10. Inventory reduction (INR)	53	6
11. Work-in-progress reduction (WIP)	80	9
12. Personnel reduction (PER)	87	21
13. Number of MT reduction (NOM)	94	11
14. Productivity increase (PROD)	88	10
15. Capacity utilization increase (CAP)	84	10
16. Unit cost reduction (UCR)	68	8

There are several directions for FMS diffusion – geographical distribution, in-time diffusion, allocation by industries and application areas. Of course, the geographical distribution among 29 countries in the

bank (see Table 2) is not an exact copy of the real diffusion, owing to a difference of availability of information from the respective countries.

Table 2

Geographical distribution of FMS installations

Country	Number of FMS installed	Share, %
1. Austria	6	0.7
2. Belgium	6	0.7
3. Bulgaria	15	1.7
4. Canada	4	0.5
5. Czechoslovakia	23	2.6
6. Finland	12	1.4
7. France	72	8.2
8. Federal Republic of Germany	85	9.7
9. German Democratic Republic	30	3.4
10. Hungary	7	0.8
11. India	1	0.1
12. Ireland	1	0.1
13. Israel	2	0.2
14. Italy	40	4.5
15. Japan	213	24.2
16. Netherlands	8	0.9
17. Norway	1	0.1
18. Poland	5	0.6
19. Romania	1	0.1
20. Singapore	1	0.1
21. Republic of Korea	4	0.5
22. Spain	2	0.2
23. Sweden	37	4.2
24. Switzerland	6	0.7
25. Taiwan, province of China	5	0.6
26. United Kingdom	97	11.0
27. United States of America	139	15.8
28. USSR	56	6.4
29. Yugoslavia	1	0.1
Total East	138	15.7
Total West	742	84.3
Total	880	100.0

It is obvious from Table 2 that there are two leaders among the countries — Japan and the United States of America (24% and 16% of the total FMS population, respectively). The second group includes those countries with a share of 5-11% — France, the Federal Republic of Germany, the United Kingdom and the USSR. Czechoslovakia, the German

Democratic Republic, Italy and Sweden own 2.5-5% of the total FMS population each. The share of the USSR looks underestimated due to a lack of published data. The share of all other 19 countries is 10% of the total. Figure 2 shows a correlation between the number of FMS installed and the gross

national product (GNP), measured in billions of US dollars.

As is shown in Figure 3, 80% of the 755 systems (where year of installation was reported) were installed in the 1980s. In reality this share is even higher, as the main sources we used were prepared in 1986-1987 and the information on the systems installed in 1986-1988 is incomplete. According to our estimates, the total FMS population in the world was around 1000 in 1988 and more than 75% of all FMS in the world are now less than five years old. According to our forecast, the world FMS population will reach 3000-3500 units in year 2000 and it will grow mainly owing to the widening of the "user's club" and to new areas of application (assembly, continuous processes, etc.).

The FMS distribution by industries shows that about half of the systems are used in the transportation equipment industry, mainly in car and tractor production and in aerospace. The second main user is non-electrical machinery, mainly machine-tool building, and the third one is electrical machinery.

The technological processes in car components, large electrical machines, and machine-tool production, are very similar. This is why there are only two aggregated industrial sectors shown in the bank:

1. Transportation equipment, non-electrical machinery, large electrical machines (IND1);
2. Electronics and instruments (IND2).

Approximately 90% of 870 FMS are allocated in the first sector and only 10% in the second. The share of

the latter reaches 16% in Japan (according to MITI 88 - 18%). But the process of the real FMS diffusion in the second sector began only in 1982-83.

On average, 76% of FMS are involved in machining (metal-cutting) processes (APP2), 8% in manufacturing (non-machining processes, like plating, combination of different processes like machining and assembly) (APP1), 8% of FMS form metal sheets (APP3) and the other 8% are used in welding and assembly (APP4 + 5).

For the systems installed in IND2, the shares differ. Only 24% are used in machining, but 29% in metal-forming and 32% in welding and assembly. Chronologically, assembly FMS as well as combining machining and assembly processes appeared much later than pure machining systems, but the growth rate of the former was higher, on average, during later years than the growth rate for FMS as a whole (see Figure 4).

It means that the future growth of FMS technologies will be based not only on the spreading of their implementation in traditional niches (metal-cutting and metal-forming) but on a rapid growth of new niches (assembly and manufacturing), and especially in electronics and instruments.

In reality, the total FMS population is a "mixed salad" including systems of different technical complexity, producing different types of parts by different modes. As a result, they have different economic advantages (lower cost, higher flexibility etc.). The figures given in Table 3 demonstrate examples of FMS used in different areas of application.

Figure 2. Number of FMS installed versus GNP by main countries

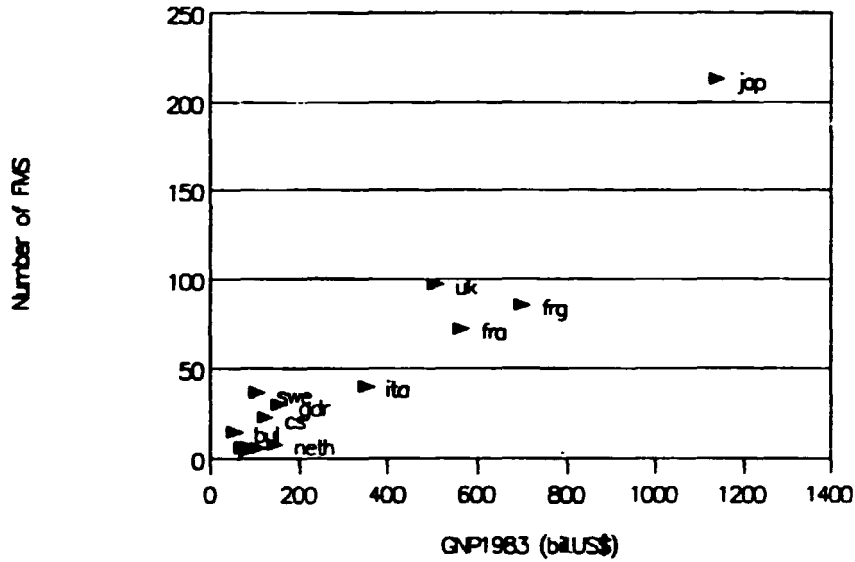


Figure 3. FMS population growth by countries (No of FMS installed)

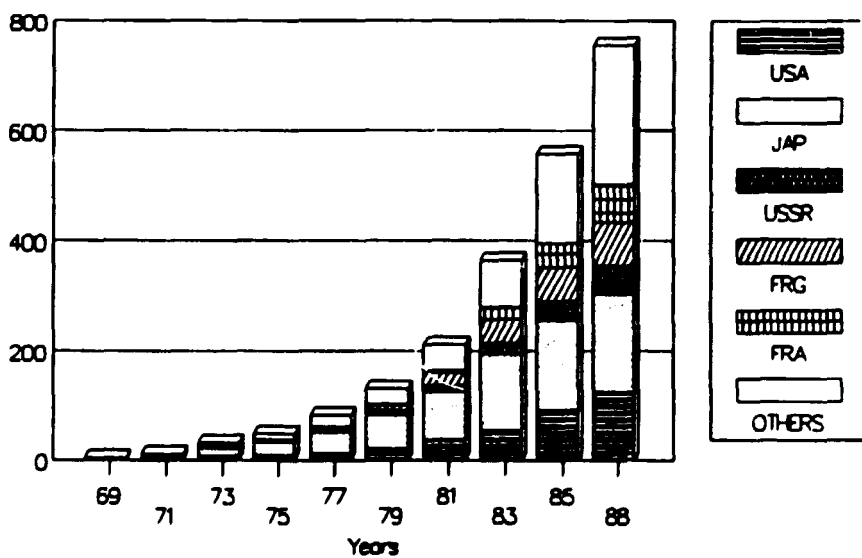


Table 3

The average FMS characteristics by areas of application

Indicators	APP2*	APP2	APP3	APP4 + 5	Total
Number of NC-machines (NCMT)	3/10	6.9	3.9	18	7.1
Number of robots (ROB)	1-2	3.1	1.7	29	6.8
Technical complexity (TC)**	3	4.4	1.9	9.4	4.6
Operation rate (OPR)	3	2.7	2.3	2.4	2.6
Number of unmanned shifts (UNM)	1	1.0	0.8	1.6	1.0
Number of product variants (PV)	1-50	163	1138	88	216
Batch size, units (BS)	1-50	207	71	324	188
Investments, \$US mill. (INV)	2/16	5.7	3.1	5.9	5.6
Pay-back time, years (PBT)	3	3.8	3.1	3.6	3.8
Change by a factor of:					
Lead time reduction (LTR)	2/10	5.1	9.5	10.1	5.4
In-process time reduction (IPT)	2/10	7.3	4.0	4.1	5.9
Inventory reduction (INR)	2/4	3.9	***	***	4.2
Work-in-progress reduction (WIP)	2	3.7	***	***	4.0
Personnel reduction (PER)	2	4.2	1.8	4.1	3.9
Number of machines reduction (NOM)	3	4.0	***	***	4.1
Floor space reduction (FLS)	2	3.1	1.7	2.2	2.8
Capacity utilization increase (CAP)	1.5	1.8	***	***	1.8
Unit cost reduction (UCR)	1.3	1.7	2.4	2.4	1.8

- * A peak of the FMS distribution over the indicator. Slash means that there are two peaks in the distribution.
- ** Index $TC = 0.7 MC + 0.35 NC + 0.3 ROB + 0.3 TRT$, where: MC - number of machining centers, NC - number of other NC- machine tools, TRT - type of transportation system (1 or 2).
- *** Number of observations is not enough for averaging. As the average figures are more or less shifted due to the presence of several untypical FMS in the samples, to present a "portrait" of a typical FMS it is reasonable to take the distribution estimates (APP2*) into consideration (Tchijov 89). To analyze some temporal tendencies in changes of typical FMS figures the whole sample was clustered into several subsets (generations) according to the years of installation. Thus, the analysis will be based on a comparison of average figures for each generation.

One can observe that metal-forming FMS (APP3) have a lower average number of NC-machines, a lower technical complexity index, and a lower

operation rate, batch size, investment cost and pay-back time. They have higher numbers of product variants and lead-time reductions. On the other hand,

welding and assembly FMS (APP4 + 5) both contain more NC-machines and industrial robots. They are also used longer in unmanned regimes, for production of smaller numbers of product variants, but by larger batches, and with very high lead-time reductions.

In order to avoid mixing different types of FMS applied in different areas in the analysis of dynamic tendencies described below, we have chosen machining systems and manufacturing FMS, where machining processes dominate, as a background sample. In total, there are 649 such systems in the bank where the year of installation was reported.

The changes of technical complexity (TC) over time are shown in Figure 5. One can observe a growing tendency of the average technical complexity index from 4 at the beginning, up to 5 in 1986, and a certain decline afterwards. This result confirms the information that today the main FMS vendors are simplifying FMS in order to standardize them and make them more marketable and attractive for new adopters. The same tendencies are demonstrated in the United States and Japanese cases. The former passed a technical complexity peak in 1986, while the latter had passed it in 1983 (Tchijov 89,3).

Among the reasons for such a tendency in TC changes is a distinct decline in the number of NC-machines per FMS (NCMT), which is shown in Figure 5. At the same time, the share of machining centers in NCMT is increasing, while the average number of MC in a system looks relatively stable. For the FMS where robot use was reported, a strong growth of the average number per system was observable: from 1.3 to 3.0 for the period. The share of FMS served by flexible computerized transportation sub-systems increased from 10% in the first half of the 1970s up to 60% in the second half of the 1980s.

From the data analysis it is possible to derive the following conclusion. In the 1980s the tendency towards a higher technical complexity encountered a number of obstacles. First of all, the experience in FMS usage indicated that from the economic viewpoint some expensive sub-systems were not viable and increased the pay-back time. Secondly, certain limits to the growth of the number of machines are connected with hyperbolically increasing software costs when the number of pieces under computerized control is increasing. The third reason for TC stabilization, or even decrease, is the growth of the FMS world market. Highly sophisticated FMS could be invested in and managed by big companies sufficiently experienced in high-tech use. But in the

1980s many new FMS adopters came on the market, and some of these were relatively small companies, often subsidized by government organizations. Having no experience in FMS use, they demanded relatively simple and inexpensive systems.

FMS investment cost (see Figure 6) was going up until the beginning of the 1980s, then down and up again in 1987/88. Roughly, it could be treated as a stable cost equal to \$US 5 million. But the deflation of the indicator by the industrial equipment price index shows a definite decline of FMS investment costs from 4 to 1.7 million 1967 dollars. This process is a result of the growing sophistication of FMS until the middle of the 1980s, compensated for by a relative price decrease for its main elements, especially computer hardware.

In order to avoid disturbances in flexibility averaging caused by several cases where extremely high PV and BS values were reported, these values were restricted to 1000. After these changes, we obtained some PV fluctuations in time, but around a horizontal axis at a level of 120 product variants. A certain increase of FMS flexibility over time is demonstrated by a decrease of the average batch size, as well as by an increase of the PV/BS ratio (see Figure 7).

The relative FMS advantages were reported in a minority of the cases in the bank. This is why we are able to assess the trends only for aggregated time intervals. Results for the selected indicator are shown in Figure 8.

The really strong growth in lead-time (LTR) and work-in-progress (WIP) reductions, when FMS replaced conventional technologies, is clear especially from the beginning of the 1980s. Finally, FMS implementation led to lead-time reduction by 80-90% and to WIP reduction by 75-80% in 1985-1988.

Definite positive tendencies are demonstrated for fixed capital indicators, namely the number of machines reduced and an increase of capacity utilization. The analogous figures for the personnel and floor space reduction do not show any increase of the indicators in time. The results stress the relatively low importance of floor space saving in the total cost reduction. Labor saving was more important when the first FMS were installed. That was why their implementation provided personnel reductions by a factor of 4-5. Later this driving force played a less important role, and the cost of a further increase of the indicator made additional labor saving unreasonable.

Figure 4. Trends in FMS distribution by areas of application (APP), %

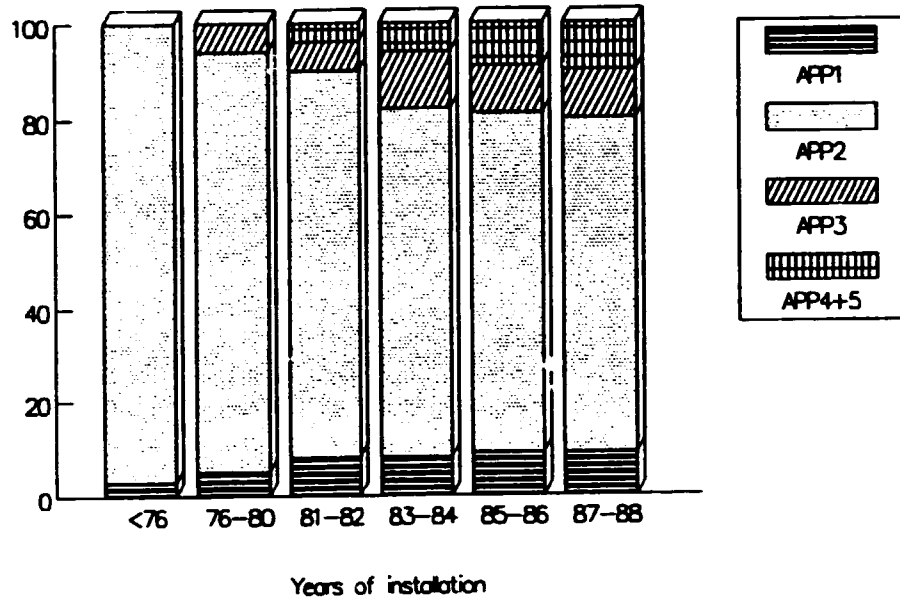


Figure 5. Technical complexity (TC) and NCMT trends (MC/NCMT - in brackets)

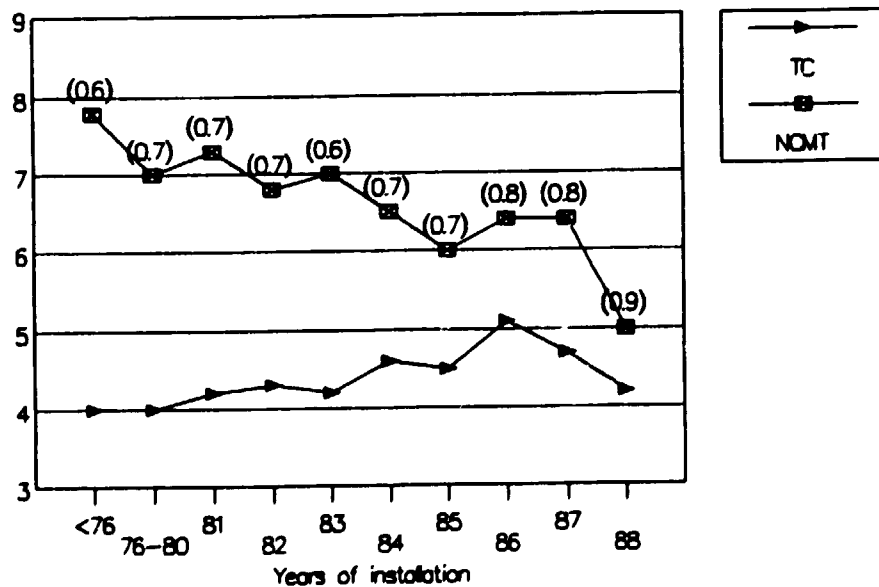


Figure 6. FMS investment trends (M.US\$)

INV- in current, INV67- in 1967 prices

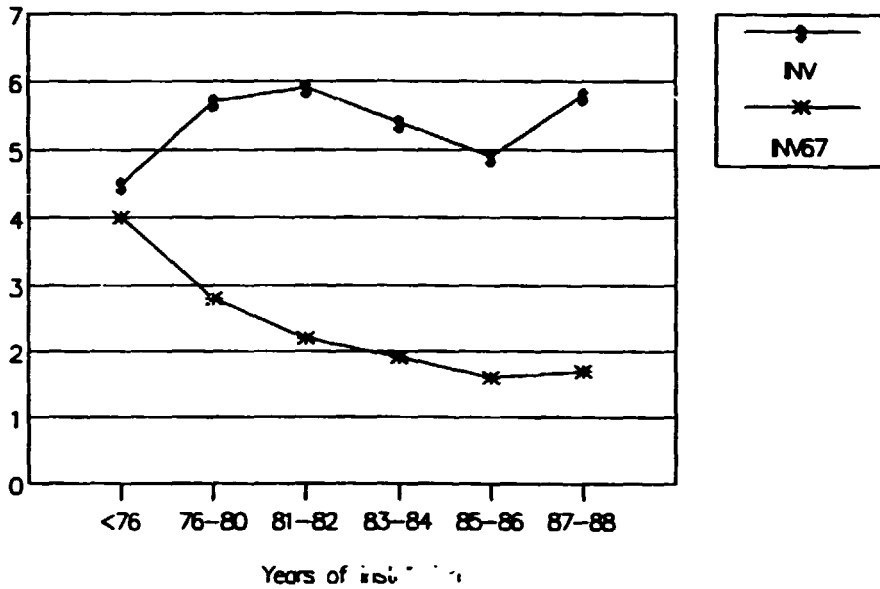
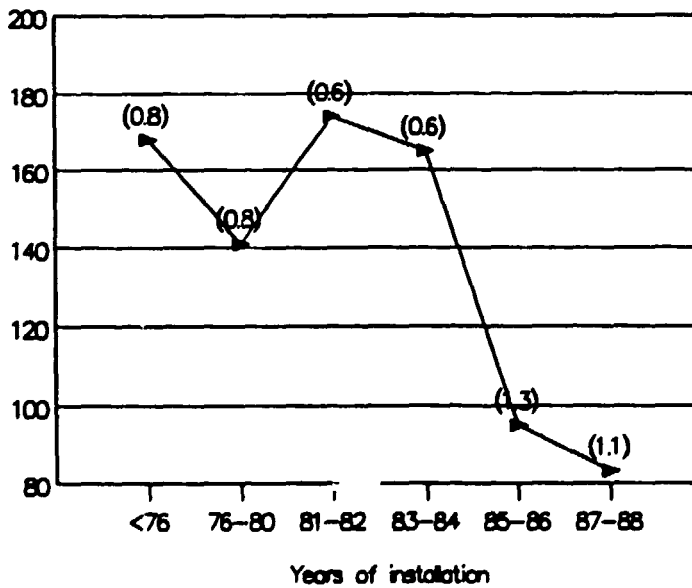


Figure 7. Average batch size (BS,units)

trend, PV/BS ratio is in brackets



The unit cost reduction (UCR) is more moderate by nature than the above-mentioned indicators, but a certain tendency towards growth of the indicator is observable. In the 1970s, the cost of a unit produced by an FMS was 80% of the cost of the same unit produced by a conventional technology; later it dropped to 50-65%. As a result of FMS development and improved usage, especially connected with better management, the pay-back time displayed a distinct tendency to decrease: from 4.1 to 3.5 years (see Figure 8).

FMS diffusion expanded rapidly in the 1980s, and new industries (electronics, instruments) as well non-traditional areas of application (assembly, welding, EDM, plating, etc.) have become new niches for FMS implementation. Nevertheless, the majority of the current FMS population is installed for the traditional machining of prismatic case-type or rotational parts in non-electrical and electrical machinery, as well as in transportation equipment production.

Each new FMS generation has had a higher technical complexity than its predecessor, due to more machining centers and robots included in the new FMS generation. This has been supplemented by more intelligent transportation, storage and inspection systems. This was a natural way of technological development until the middle of the 1980s.

After the peak, a certain stabilization of sophistication processes is observable. We find that one of the main reasons for such a change is the following. At that time FMS left the embryonic phase of their introduction, when the main focus was on technical problems. The first adopters had passed through a learning curve and FMS appeared on the market. The FMS user's club became widespread and in this situation economic, managerial and social factors began to play a much more important role in the success or failure of FMS than technical factors.

Looking through the trends shown above, one can see that there were two periods of significant improvements of FMS relative advantages: at the end of the 1970s and the beginning of the 1980s and in the period 1987/88. The first wave could be explained by passing through a learning curve and coinciding with the first period of mass FMS implementation. The second one reflects a certain overcoming of software and socio-managerial problems, though the latter still exists in some companies and countries.

3. INTERNATIONAL COMPARISON OF FMS DIFFUSION

The FMS data bank now contains considerable information, enough to make quite substantial international comparisons possible. This can be used in different ways: to make comparisons between several leading countries, like the Federal Republic of Germany, Japan, the United Kingdom and the United States; and for the purposes of East-West comparisons. More detailed comparisons are available in (Tchijov 89, 2).

It is fairly clear that, in general, technically complex systems must cost more than the simpler ones, and this is statistically confirmed by our data. But the technical complexity (TC) - investment (INV) relationship depends significantly on the country where the FMS is installed. For the main national FMS users, we have obtained the linear regression between investment and technical complexity index (shown in Figure 9). This result is also confirmed by the data, showing that Japanese FMS have a development cost approximately 0.4 million yen lower than corresponding systems in other countries (Furukawa 86).

The relatively high investment cost of United States FMS could be explained in four ways (see also (Akamatsu 88), (Baranson 87), (Furukawa 86), (Jaikumar 89), (Merchant 85-88), (Yamashina, *et al.* 89)). The first reason is connected with different systems of calculation. FMS in the United States are usually bought as turnkey systems, while in other countries some of the investment components are covered within the company (e.g. software or supporting sub-systems development) and are not included in the investment cost.

The second reason is the installation strategy. Japanese companies spend up to two years over extremely careful pre-installation planning, choosing optimal FMS architectures and future operational modes. The systems are usually started from a zero level and consequently are compatible with the enterprise environment, while in the United States some FMS were integrated into existing infrastructures and production processes.

The third reason is connected with the use of extremely expensive FMS by military-oriented giants of the United States and United Kingdom industries: ITV, General Dynamics, Lockheed, McDonnell-Douglas, British Aerospace, Rolls-Royce.

The fourth reason is the use of different automation policies. One of the main driving forces of FMS installation in Japan is the improvement of competitive positions through production cost reductions. In the United States, quality improvement plays a more important role. Its FMS are more expensive (having the same TC) owing to the high share of in-process quality control systems, while their use in other countries is relatively rare.

Figure 10 shows that Japanese FMS have the highest flexibility (measured as an average number of product variants (PV) batch size (BS) ratio), followed by the United States, Federal Republic of Germany and United Kingdom. Higher flexibility provides a larger lead-time reduction, which is 20% greater in Japan, than in the United States, and about 50% larger than in the Federal Republic of Germany and United Kingdom. The super flexible and super inflexible systems (PV/BS is more than 5 or less than 0.1, respectively) demonstrate lower efficiency indicators than the FMS with medium flexibility (PV/BS = 0.1-5). This is true for lead-time, work-in-progress and personnel reductions.

Among the relative FMS advantages, lead-time reduction plays one of the most important roles in the context of flexibility. The average figures for this indicator, shown in Figure 10, display the highest flexibility in the case of Japanese FMS. Lead time was cut by a factor of 6.8. The lowest record among the four countries was registered in the British industry (4.4), but even this figure might be regarded as a

considerable improvement. The higher flexibility, measured as the ratio of a number of product variants to the average batch size, corresponds to a higher average lead-time reduction.

The other FMS advantages, namely work-in-progress, personnel, and unit cost reductions, are shown in Figure 11. The highest advantages in WIP are found in the United States FMS (by a factor of 4.5), while the average WIP reduction reached only 3.5 in the United Kingdom and 2.3 in Japan.

The highest record in labor saving is demonstrated by Japanese companies. They reduced personnel, in comparison with previous technology, by a factor of 6, while United States companies reached only 4.7. On the other hand, the reduction of the number of machines is the highest in the United States by approximately a factor of 8, while its main competitors decreased the number of machines only by a factor of 3 to 4.

The reduction in these different cost elements is finally reflected in the unit cost reduction (UCR), and average values of the latter for the four countries are also shown in Figure 11. Owing to the relatively small number of national cases where the UCR value was reported, the cross-country comparison is not considered very reliable. The average reduction lies between 1.5 in the Federal Republic of Germany (for 11 cases) and 2.5 in the United Kingdom (but for four cases only). The ranking shown in Table 4 generally reflects the real situation in the main user countries.

Table 4

Ranking of main FMS users (1 = best)

Country	TC	PBT	PV/BS	WIP	PER	NOM	LTR	UCR
Federal Republic of Germany	3	4	4	4	3	4	3	4
Japan	2	3	1	3	1	2	1	3
United Kingdom	4	1	3	2	4	3	4	1
United States	1	2	2	1	2	1	2	2

Figure 8. Trends in FMS indicators, PBT

- years, others- changes by a factor of

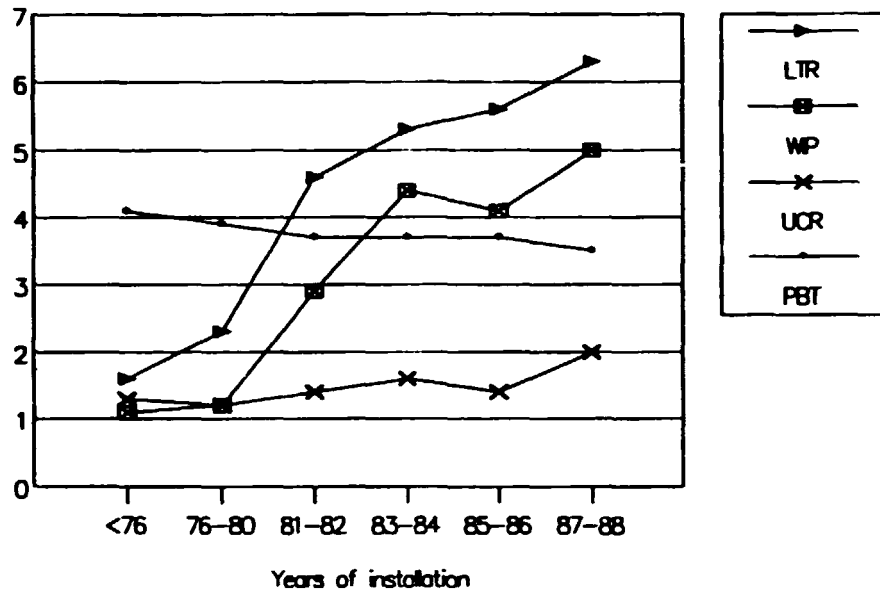


Figure 9. FMS cost-complexity relation

by countries

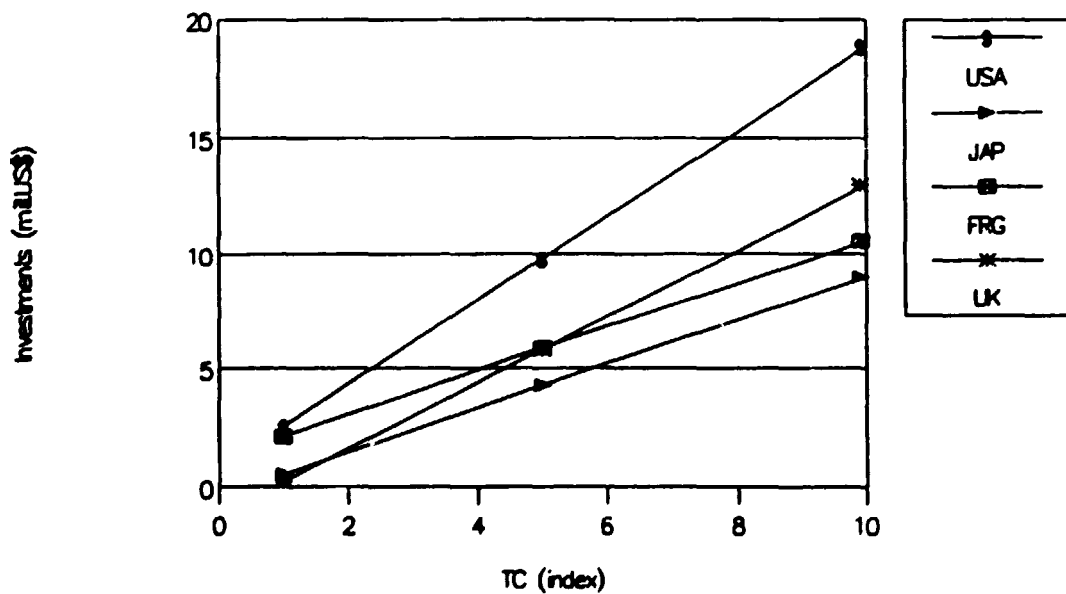


Figure 10. Average LTR versus PV/BS ratio by countries

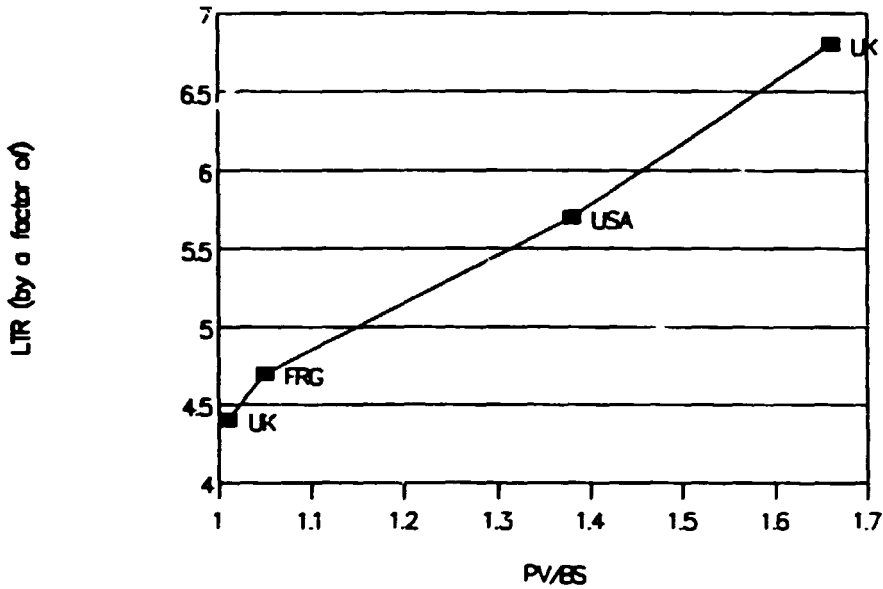
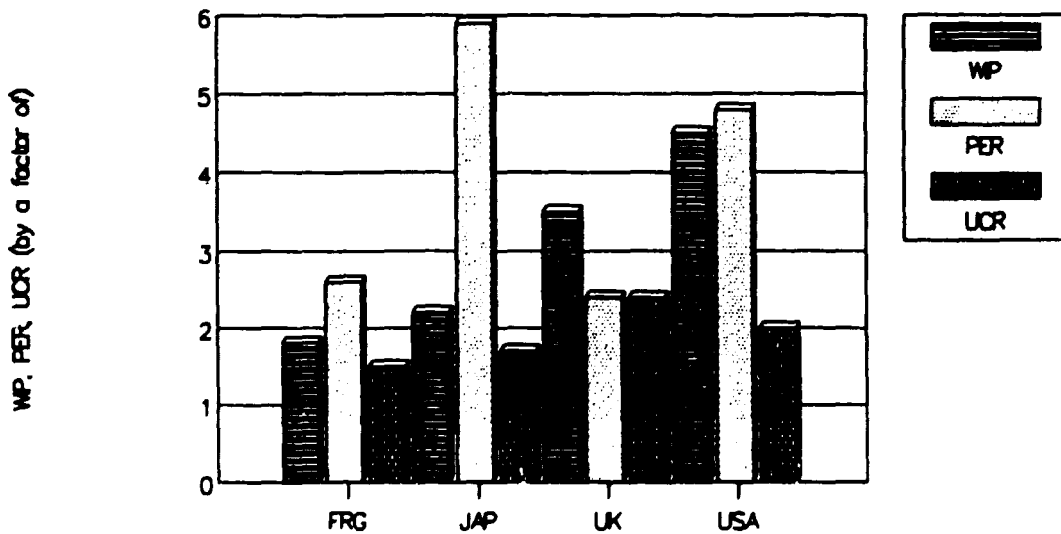


Figure 11. Average WIP, PER and UCR by countries



There are about 750 Western FMS and about 150 Eastern FMS in the data bank now, which makes East-West comparisons statistically reliable in spite of the lack of some indicators in one or other sample.

The data availability as well as average values of the main indicators are demonstrated for Eastern and Western countries in Table 5.

Table 5

East-West FMS data comparison.

Indicators	East		West	
	Number of cases	Average	Number of cases	Average
1. Number of machining centers per FMS (MC)	74	5.4	469	4.6
2. Number of NC-machines per FMS (NCMT)	119	8.5	635	6.8
3. Number of robots per FMS (ROB)	40	5.0	186	7.2
4. Technical complexity index (TC)	123	5.0	661	4.5
5. Number of product variants (PV)	88	199	437	149
6. Average batch size (BS)	67	183	192	127
7. Investments, \$US mill. (INV)	30*	4.2	284	5.7
8. Pay-back time, years (PBT)	29*	4.8	69	3.4
Reduction by a factor of				
9. Lead-time (LTR)	21*	2.9	86	6.0
10. In-process time (IPT)	32	3.6	58	7.1
11. Work-in-progress (WIP)	17	3.3	63	4.2
12. Personnel (PIR)	61	2.8	126	4.4
13. Unit cost (UCR)	14	1.6	54	1.7
Increase by a factor of				
14. Productivity (PROD)	45	2.8	43	4.0
15. Capacity utilization (CAP)	20	1.8	64	1.8

* Mainly Czechoslovak installations

In the technical complexity block (indicators 1-4), Eastern FMS have a certain advantage, measured in a greater average number of machining centers and total number of NC-machines. The lower number of robots reflects a smaller share of assembling systems in the Eastern sample. In total, the technical complexity index is slightly higher in the Eastern countries, but the difference is negligible and much less than between the main Western users.

The operation rate (2.4-2.6 shifts a day) and number of unmanned shifts (0.9-1.0) are almost the same in all the samples, but with regard to the flexibility indicators (5 and 6) there is a difference between the samples. In the Western cases, the average number of product variants and also the average batch size is less than in the Eastern cases. This could be interpreted in the following way.

There are two possible areas for the replacement of conventional technologies by FMS (for more detail, see (Ranta & Tchijov 90)). The first one is small-batch production of a large number of different products. The second one is big-batch production, where several production lines are replaced by an FMS. In the second case, the average batch size is much higher, usually amounting to several thousands. The share of the second type of substitution is much higher in the Eastern countries. Generally, the Eastern FMS are more flexible than the Western FMS in terms of a higher number of product variants, but less flexible in terms of larger batches.

The average costs of the Eastern FMS are lower than in the Western countries, but almost all the Eastern cases giving investment data came from Czechoslovakia. In spite of lower average costs, the Eastern FMS demonstrate a longer pay-back time. This could be explained by differences in pay-back time calculation in Eastern and Western systems or by a lower efficiency of FMS in Eastern countries.

The second conclusion is confirmed by the relative advantage indicators for FMS (9-15). The average lead-time and in-process-time reductions are two times lower for the Eastern countries, which reflects a certain organizational lag behind the Western countries taking place at the shop-floor level. Labor saving is lower for the Eastern industry. At the same time, there is an almost equal floor space, work-in-progress and unit cost reduction, as well as a capacity utilization increase.

Furthermore, the distributions of several indicators for Eastern and Western cases were also analyzed. We

found that there are some differences in the distributions behind the almost equal average figures for some indicators.

For example, the share of simple FMS (with a TC of 1 to 4) is the same in both samples and is equal to 60%. In the Eastern countries the systems with a TC of 3 to 4 dominate in this group (21%), while the Western systems with a TC of 1 to 2 have the highest share (22%). However, the main reason for a higher average TC in the Eastern sample is its higher share of the systems with a TC of 10 to 20 (7.5% versus 4.2% in the Western sample).

As can be seen from Figure 12, the longer pay-back time for Eastern FMS is due to the absence of cases with a PBT of less than two years and to the extremely high share of the systems with a PBT of more than five years (all of the latter belong to Czechoslovak cases).

Approximately 64% of the Western FMS produce up to 50 product variants. The analogous share of the Eastern cases is only about 44%, but the share of the Eastern systems producing more than 100 product variants is above 56%, as compared with 36% in the Western sample. The average figures are sensitive to the difference between the shares of FMS producing more than 1000 product variants (7% of the Eastern cases versus 3% of the Western cases). Some 12% of the Eastern FMS (probably replacing conventional transfer lines) produce more than 1000 parts per batch, while only 3% of the Western systems have the same production mode.

The higher average number of product variants in the Eastern countries could be explained by a lower average part complexity. As was shown in (Tchijov 89,1), the ratio of the number of machining centers to the total number of NC-machines could be used as an indicator of the part complexity (a higher ratio means a higher complexity). This ratio is slightly higher for the Western FMS.

Another example of the distribution analysis is shown in Figure 13 – for personnel reduction. In this case one could observe extremely high shares of the Eastern systems with relatively low reductions (60% with a PER of 1-2). Almost all of them belong to Czechoslovak cases. The main reason for this lagging behind of the Eastern FMS in this indicator is the relatively low share of the systems with a high efficiency. In only seven Eastern cases was the PER reported to be more than 4.

Figure 12. East-West comparison of FMS distribution (%) over pay-back time

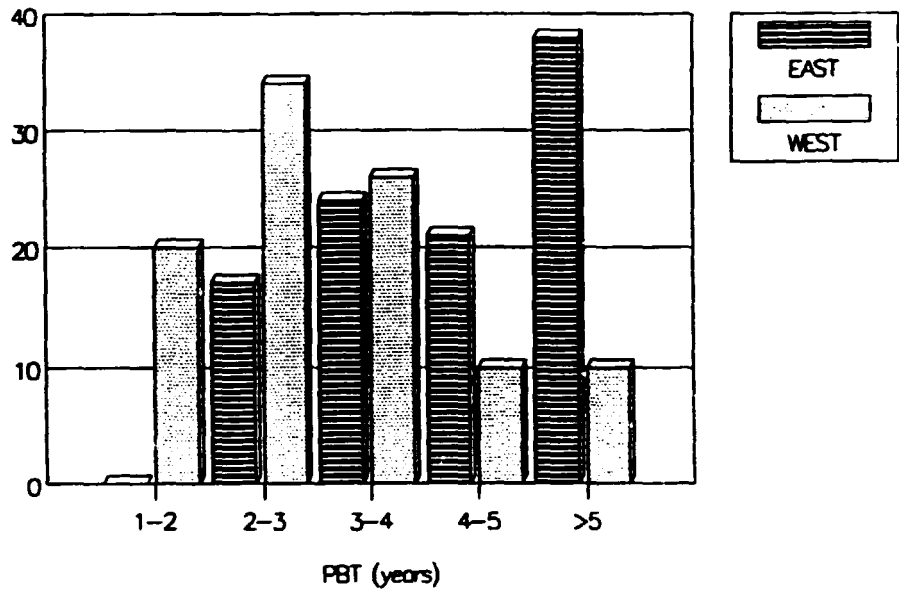
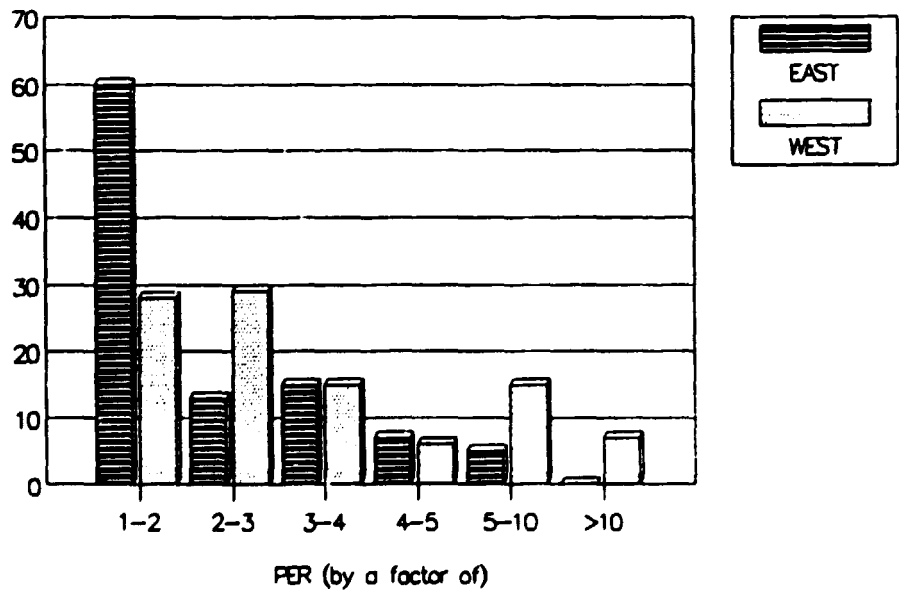


Figure 13. East-West comparison of FMS distribution (%) over personnel reduction (PER) distribution



Dealing with the indicator time trends we found some differences between the Eastern and Western patterns. A certain growth of the NC-machine tools number per FMS (NCMT) is observable for the Eastern FMS after 1982, while this indicator looks rather stable in the Western cases (see Figure 14).

The average Western FMS cost had a slight tendency to decline (in money terms), while the Eastern FMS cost was decreasing faster (see Figure 14). Again, in the pay-back time dynamics a certain converging tendency takes place. After 1982 an average PBT decrease is clearly shown for the Eastern sample in contrast with a PBT growth for the Western systems. We suppose that the first tendency could be explained by the efficiency growing from one FMS generation to another. The second tendency, for the Western cases, is probably connected with the growing share of FMS equipped with more sophisticated supplementary systems (transportation, storage and inspection).

The FMS of both East and West demonstrate a growing efficiency in terms of the set-up time reduction, but the Western curve is significantly higher than the Eastern one. Western FMS installed after 1985 reduced set-up time by a factor of 7 in comparison with their predecessors. Eastern systems of the same generation reduced the indicator by a factor of 3. The probable reason for this could be connected with organizational or managerial factors.

On the other hand, one can observe converging tendencies in some indicators, such as personnel reductions (see Figure 14). An efficiency decline takes place for the different generations of Western FMS in contrast to the growing efficiency of Eastern systems. The values of the indicators are very close to each other for the most recent FMS generations in both samples.

The above analysis of the international comparison allows us to draw some conclusions which are based on statistical averaging and which consequently show probabilistic features. Among the users of FMS in the world there are two clear leaders, Japan and the United States. Each of these countries have more than 200 FMS with a high average efficiency. These are followed by four other important users - the

Federal Republic of Germany, France, the United Kingdom and the USSR with about 100 FMS each. But the technical and economic records of these countries are usually lower than in the first two countries, though sometimes FMS installed in small but experienced countries, such as Finland or Sweden, demonstrate significantly higher efficiency.

Some important differences in FMS use in the leading countries exist. For example, the United States systems are more expensive than the others, even if we take their higher complexity into consideration. But their pay-back time is relatively moderate due to the high efficiency of their use.

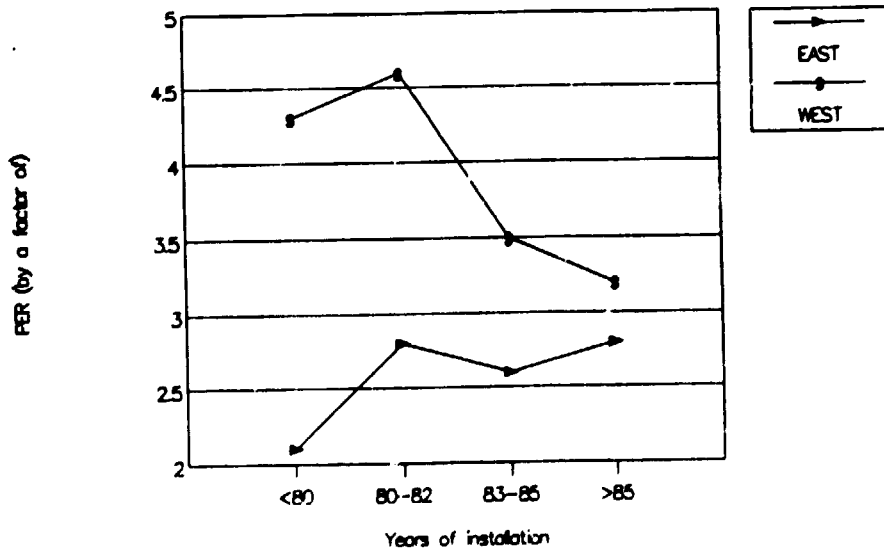
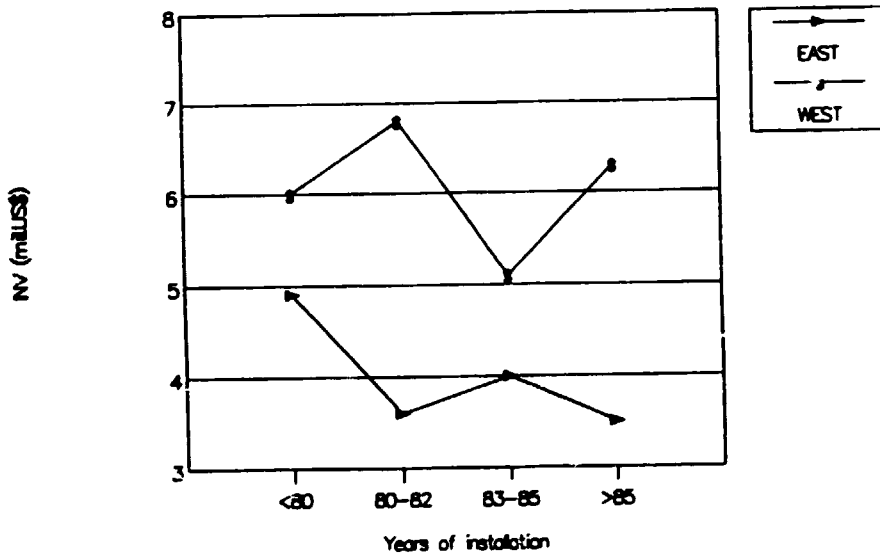
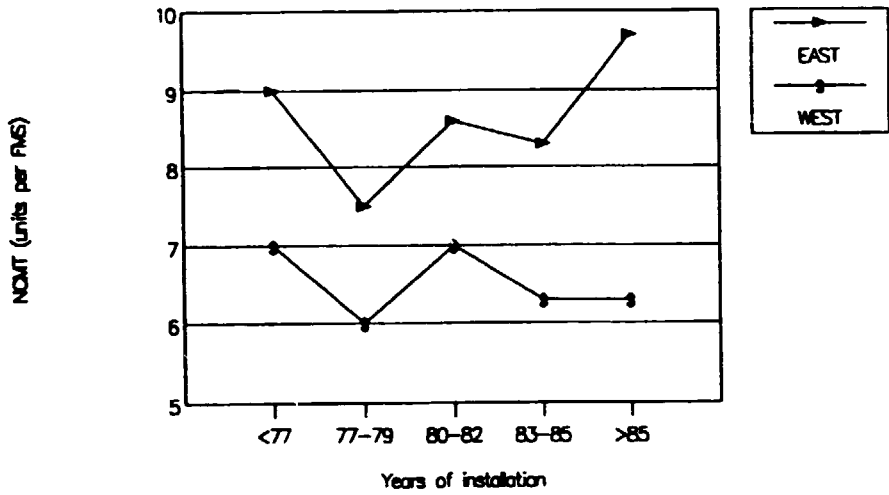
The Japanese FMS are more strongly oriented towards higher flexibility than those of the other countries, and they show the highest average lead-time reductions. Japan is also the leader in FMS use in more progressive areas, with 36% of the Western systems installed in electronics and instrument industries belonging to Japanese companies, and 31% of the FMS used in assembling operations being in Japan. The Japanese FMS also provide the highest average personnel reduction, while the United States FMS are leading in the reduction in work-in-progress and number of machines. The Federal Republic of Germany is close to the leaders in technical complexity, while the United Kingdom has a good record in achieving pay-back time and unit cost reductions.

The East-West comparisons show some advantages of the Western FMS in some efficiency indicators, e.g. in reduction in in-process time, personnel and the number of machines and, as a result, in pay-back time. At the same time, Eastern FMS show results almost equal to Western FMS with regard to technical complexity and capacity utilization increase, as well as to unit cost and floor space reduction.

The operation modes for the Eastern and Western FMS are different. The first produce more product variants but in larger average batch sizes. This could probably be explained by the higher share of FMS replacing conventional transfer lines in the Eastern countries.

Figure 14. East-West comparison of NCMT

INV and PER trends



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COSTS, BENEFITS, USER CHARACTERISTICS AND SUCCESSFUL IMPLEMENTATION STRATEGIES OF FLEXIBLE MANUFACTURING SYSTEMS: AN INTERNATIONAL COMPARISON AND SURVEY

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1. INTRODUCTION

Flexible manufacturing systems are usually associated with many benefits, such as labor and capital savings, decreased lead and delivery times, increased flexibility and the ability to adapt to changes as well as improved quality. Conventionally it has also been thought that FMS play a role between semi-manual, small-batch production and high-volume fixed automation and transfer lines, being some kind of mid-range systems which provide medium efficiency and medium flexibility (ECE (1986), Jacobsson *et al.* (1988)).

However, the conclusions in the literature seem to be rather contradictory. The benefits and the costs associated with achieving the benefits are rarely expressed. There are no clear data on how different benefits are associated with each other and how the benefits depend on the manufacturing and business environment. Some studies emphasize FMS as a possibility for small-batch production to achieve the technological advantages of mass production (Ranta *et al.* (1989b), Johnston *et al.* (1988)). On the other hand it has been claimed that FMS is not feasible for small-batch production at all (Kelley *et al.* (1988), Darrow (1987)). Many case studies emphasize the difficulties involved in making realistic cost-benefit analyses and in assessing the economic risk associated with poor design, underestimated costs and too optimistic benefit assessments (Meredith (1987 a, b, c), ECE (1986), Jaikumar (1986), Ranta *et al.* (1988c)).

Moreover, the FMS applications are still technology driven, i.e., the technology is not yet mature, there are few standard systems, and a lot of customizing is needed to develop application-specific control and communication software. All these add their own components of uncertainty and risk (Ranta (1989)). Thus we can claim that the real situation is not so easy and straightforward as stated in many optimistic prognoses. Therefore we can expect that there are many factors related to technology, application area, implementation and design practice, as well as the cultural and institutional environment, which explain

the uneven diffusion of FMS and many unintended impacts related to production economy and business strategies (see Krafcik (1988), Leppänen (1989)).

In order to understand the diffusion factors of FMS and how the conventional systems are substituted by FMS, IIASA started to collect, for its CIM project, empirical data on costs, benefits and relative advantages as well as on the implementation and design practice of FMS. The project was an attempt to understand what the typical systems and user characteristics were, how different benefits and advantages were associated with each other, and how different advantages were dependent on the application and the business environment. These basic analyses would then be used to understand the factors behind successful applications and implementation practices, they would also be used to project future applications.

Currently IIASA has data on 800 FMS in the world and 60 thorough case studies in different countries. These data can be used to analyse the characteristics of relative advantages and the interconnections among the advantages. Technological characteristics and factors behind costs and benefits are then studied and their role with regard to the benefits and the type of substitution of conventional systems is explained. We are mainly interested in understanding and explaining the impact of systems software on the costs and application characteristics, and whether there is any empirical evidence that software and other technical obstacles are the factors behind the two typical categories of successful systems. We are also interested in assessing the typical benefits in different manufacturing environments, and how the benefits are dependent on the way in which the conventional system is replaced and on the goal of the system implementation. Moreover, we are interested in using the case study data to evaluate the key obstacles and risks in FMS implementation.

The second part of this paper gives the background on the project's databases as well as on the case studies done for the project. The third part of this paper explains the cost-benefit characteristics and also

describes typical substitution paths of conventional systems. The fourth part of this paper looks at the relationships between different benefits, and the fifth part of this paper explains different successful implementation strategies. The more comprehensive statistical and economic data can be found in earlier IIASA publications (Tchijov (1989), Tchijov *et al.* (1988), Tchijov (1989a, b), Maly (1988), Ranta (1989a, b), Ranta *et al.* (1988a, b).

2. COST-BENEFIT INDICATORS AND FMS DATABASES

In order to analyse achieved benefits and related costs of FMS, to see how different benefits are interrelated with each other, as well as to find possible regular patterns and tendencies in benefits, a FMS database was built up by the IIASA CIM project. This database describes FMS by 32 key indicators, see (Tchijov *et al.* (1988), Tchijov (1989a, b), Tchijov *et al.* (1989)):

1. Identification and application data (company, vendor, industrial sector, application data);
2. Technical data (number of CNC-machines, of robots, type of transportation, etc.);
3. Economic and operational data (investment cost, number of shifts in use, number of unmanned shifts, pay-back time);
4. Data on benefits and advantages
 - Time reductions (lead time, set-up time, in-process time, machining time)
 - Capital cost reductions (inventory, work-in-process, number of machines)
 - Productivity and unit improvements (labor reduction, capacity increase, productivity, unit cost reduction).

The data have been collected through public sources and with the help of IIASA's collaborators. The data have been checked by our collaborators in different countries.

As of March 1989, the database consists of 800 FMS (see Table 1). The number of systems is already so

high that it allows correlations to be made between indicators and dependencies and regular patterns to be looked for between indicators.

In order to get a more detailed and thorough picture and to support the statistical analysis, the project has conducted guided case studies on FMS implementation. The project prepared a framework for a questionnaire and interviews, and the project's collaborators in different countries have conducted interviews with company managers, operators and systems planners. The project now has 60 cases in its database, describing technical characteristics of systems, investment costs and cost shares, implementation goals, expected and achieved benefits, organizational and work environment changes, training and training methods, managerial, planning and logistic issues of FMS applications. In total, the questionnaire consists of more than 300 questions. These questionnaire data can be used to test hypotheses and verify conclusions drawn from the statistical analysis (Maly (1988), Ranta (1989b)).

In the following sections these databases are used to assess cost-benefit relationships, to describe typical applications, and to draw conclusions on the successful implementation practice.

3. ECONOMIC BENEFITS AND MAIN APPLICATIONS OF FMS

Table 1 shows the estimated growth rate of the cumulative number of implemented systems.

In the spring of 1989, it was estimated that there were around 1,200 systems world-wide, which had at least two CNC-machines or machining centers, automated material handling devices and equipment, as well as a systems level central control to co-ordinate and to operate the systems as a whole. The growth rate of the new installations has, in recent years, been around 20 per cent. If this growth rate continues, there will be several thousand systems in the world by the year 2000; and even though a saturation of the diffusion process and many application barriers are expected, it is safe to say that there will be 2,500-3,500 systems in use at the end of the century or a 15 per cent annual growth rate of the FMS population in 1988-2000.

Table 1.
Implemented FMS and future systems

Year	Total Number	Compact Systems	High Efficiency System
1980	80	20	60
1988	1000	800	200
2000	3000 ¹⁾	1600 ²⁾	1400 ³⁾

- 1) Estimated: The annual growth rate of the total number of FMS is estimated to be 15 per cent.
 2) Estimated: The annual growth rate of compact systems is expected to be 12 per cent.
 3) Estimated: The annual growth rate of high capacity systems is expected to be 20 per cent.

The future patterns for the traditional applications of FMS (electrical and non-electrical machinery, transportation equipment, instruments and electronics production) in industrialized countries are relatively clear now. But the potential impact of new areas (such as furniture, wood, clothing) as well as new potential countries in the total FMS population are rather indefinite yet. This is why the forecast is mainly based on the extrapolation of the current tendencies and may be underestimated.

In any case, it can be concluded that the strategic and the major part of the production of the metal-working industries in the industrialized countries will be produced by FMS or other cell-like systems.

A direct correlation between the costs and the effects (benefits) usually showed indefinite clouds of points, or rather contradictory tendencies. This necessitated the use of FMS subclasses to obtain a reasonable correlation and explanations. Several variables were used for classification: investments, industries of application (machinery and transportation equipment versus electronics and instruments), types of FMS (machining, metal-forming, assembling, etc.) and in some cases countries, when we were not quite sure of the reliability of the investment or exchange rate data.

The FMS distribution over the investment costs shown in Table 2 demonstrates that the total FMS population can be divided into two large groups: "cheap" systems costing less than four million dollars,

and "expensive" ones costing more than four million dollars.

The distribution presented in Table 2 reflects, of course, the technical complexity of the systems in terms of the number of CNC-tools and the systems control architecture. The analysis of the distribution of the systems over the number of installed CNC-tools indicates that the correlation exists. However, the number of CNC-tools alone does not explain the investment cost distribution, we also have to look at the systems architecture and software costs for the explanation.

A typical compact, "cheap" system (see Ranta *et al.* (1988b), Shah (1987)) consists of 2-4 CNC-tool or machining centers, conveyor and/or automatic storage and retrieval system and two robots for material handling and has a programmable controller for systems control. Usually the costs of the system are less than 3M\$ and the cost break-down is approximately the following: CNC-machines 50-55 per cent, material handling and robots 15-20 per cent, control, communication and other systems-level software 20-25 per cent, planning and training 10 per cent.

It is also typical that the systems architecture of the compact system is closed so that it is hard to extend and to add new features without major new investments. This can also be a major economic risk of investment. The technologies used for the system realization, as e.g. programmable controllers or small-

capacity computers with a simple communication solution as well as limited capacity for transportation and storage, make the system difficult to expand economically. Usually a major revision is needed as well as a new solution for the systems control. Therefore the system can be called close – it has a limited expandability and adaptability. On the other hand, the system has relatively low starting investments.

A typical large-scale, "expensive" system consists (see Shah (1987), Bose (1988)) of 15-30 CNC-tools, automated guided vehicles (AGV) and an automated storage and retrieval system for material handling, a local area network and distributed microcomputer-based cell and machine control systems and usually two VAX-type computers for co-ordination, scheduling and database management. It usually has a backup computer system to secure the availability of the system and advanced algorithms and a software system for the co-ordination of the system. The average costs are 10-15 M\$ and the cost break-down is approximately the following: CNC-machines 35-40 per cent, transportation and material handling 15 per cent, control and communication and other system software 25-30 per cent, and planning and training 15-20 per cent.

It is also typical that the systems architecture is open and systems can be extended in a step-wise manner and new features can be added without a major new design effort. Because of the technology used, there is usually some reserve capacity to expand the system: some new features, like machining centers, more AGVs, can also be added. The communication and computer system provides support for such additions, as common interfacing is used. Of course, this open system structure and expandability has been achieved by relatively high starting investments.

Thus we can see also that the expanding systems structure will typically lead to an increasing software complexity and a more complex control architecture.

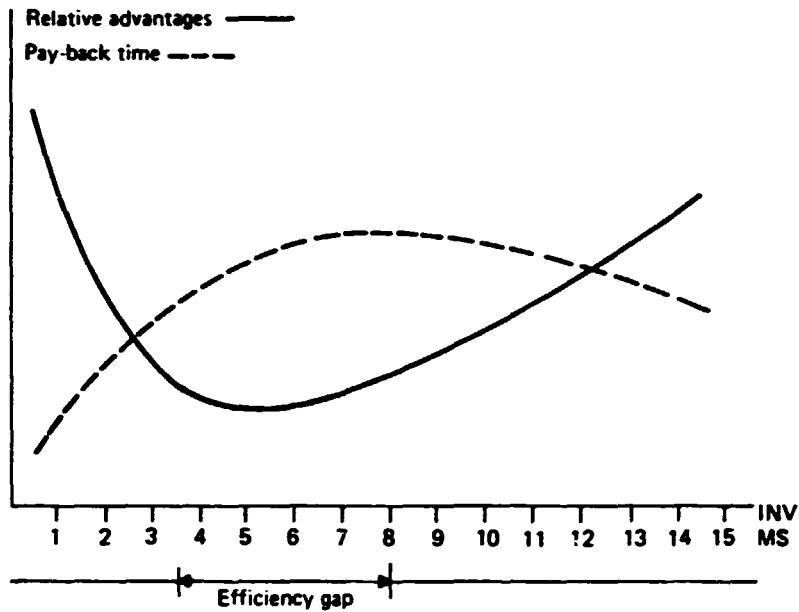
We can call those systems, which are between these two basic categories, mid-range systems. Typically the investment costs are between 4-8 M\$ and the system consists of 5-10 CNC-machines, and most likely also of automated guided vehicles for transportation. The overall control is based on super-minicomputers and the system may even have a local area network for co-ordination and communication. The systems are relatively expensive, the total cost per CNC-tool rate is quite high, but their efficiency lies only in the mid-range.

Table 2.

FMS distribution over investments (293 cases documented)

Investments, in M. US\$				
0-5	5-10	10-15	15-20	> 30
188	68	17	17	9
64%	23%	6%	4%	3%

Figure 1a. Efficiency and investment costs of FMS



- Total costs	3MS	- Total cost	10-15 MS
- CNC	50-55%	- CNC	35-40%
- Material handling	15-20%	- Transport + mat. handl.	15%
- Cont. commun. software	20-25%	- Cont. commun. software	25-30%
- Planning + training	10%	- Planning + training	15-20%

All these three basic categories also show different cost-efficiency figures, which will be explained in more detail below.

Table 3 and Figure 1a summarize the characteristics of the system as well as the different cost-benefit figures.

These figures demonstrate a typical V-shaped form of the relative benefit measures. Thus it seems that:

- the compact and small-scale systems have the best cost-benefit ratio;
- the medium-range systems are inefficient from the viewpoint of their economic justification;
- only relatively large investments and relatively complex systems provide the same efficiency and

roughly the same cost-benefit ratio as the compact systems.

From Figure 1b it may be seen that the increased capacity of systems and the increased complexity will increase the systems cost/machining unit in a step-wise manner. This is due to the need for more efficient machinery when a certain level of complexity is reached. In small-size systems it is enough to have a compact-type material handling system, like a conveyor, and simple systems control based on programmable logic. When the complexity increases, a more sophisticated material handling system is needed, like automated guided vehicles, and the systems control has to be based on computers, distributed databases and integrating communication systems. These changes in systems complexity tend to change in a step-wise manner.

Figure 1b. Technological factors of relative costs of FMS

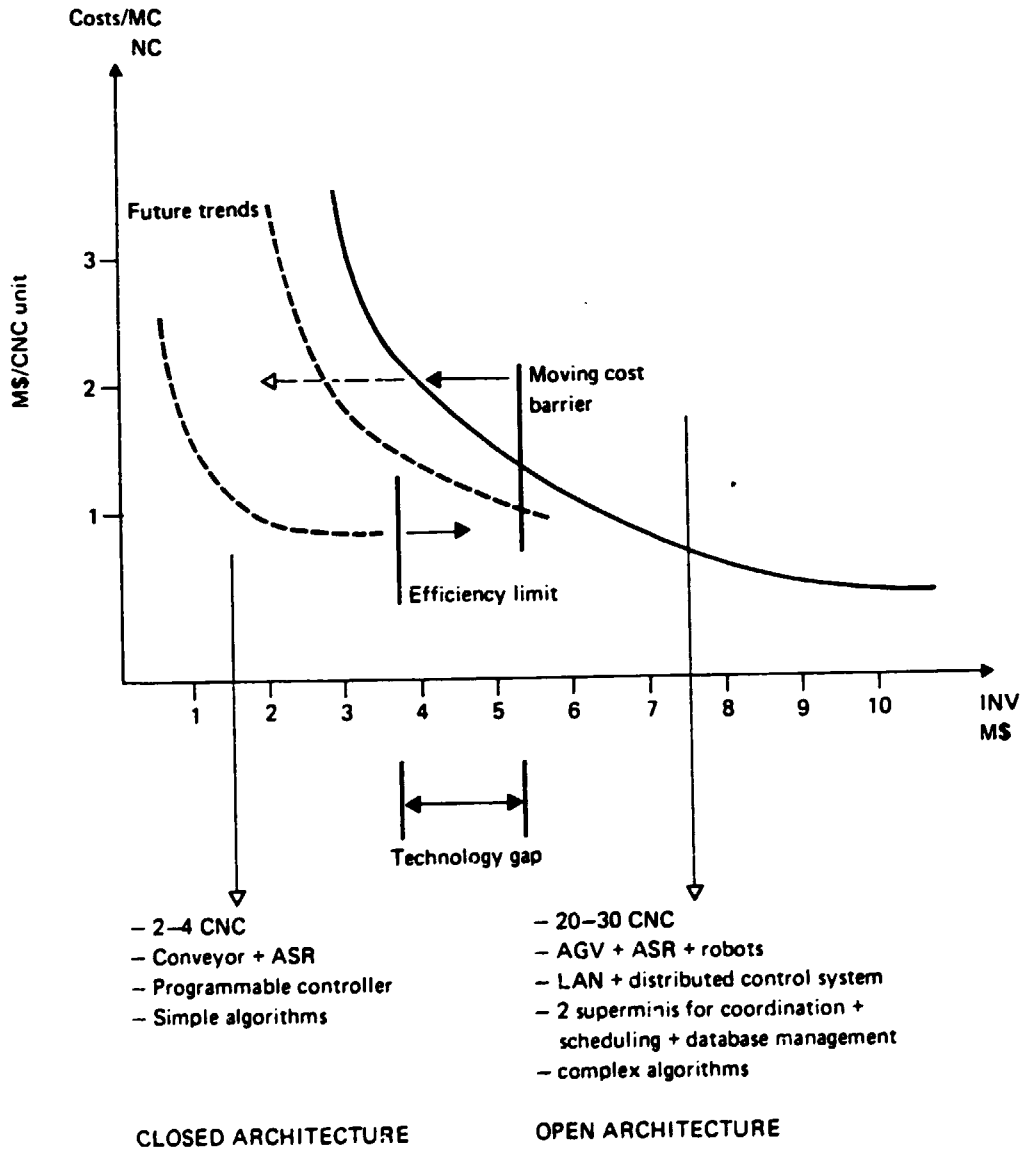


Table 3a.

The Typical Characteristics of Three Basic Groups of FMS

	Total costs (millions of US dollars)	Costs, percentage of						Control architecture	Algorithms
		CNC	Material handling	System Software	Planning Training	Number of CNC			
A. Compact systems	3	50-55	15-20	20-25	10	2-4	Closed centralized 1-2	"Simple" scheduling	
B. Mid-range systems	4-9	40-50	15	25	15	5-15	Semi-open distributed 2-3 levels	Complex scheduling & tool management	
C. High capacity systems	10-15	35-40	15	25-30	15-20	15-20	Open distributed LAN-based 3-4 levels	Complex scheduling tool management & diagnostics	

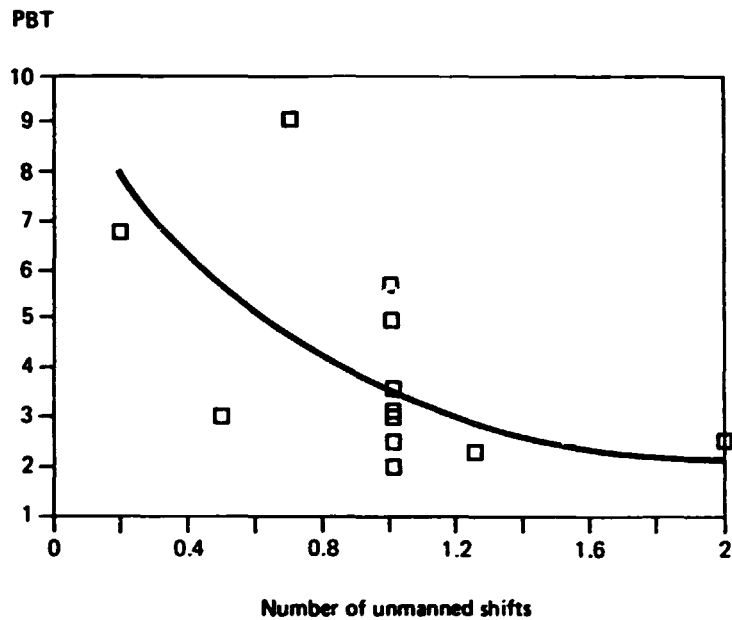
Table 3b.

Relative advantages of systems

	Relative benefits *	Pay-back time
A. Compact	3-7	1.5-3.5
B. Mid-range	1-3	5 -
C. High capacity	3-7	1.5-4

*/ Work in progress reduction, lead-time reduction, labor reduction or capacity increase, etc. The figure expresses the relative reduction factor x ($1/X \cdot A$) or relative increase factor x ($x \cdot A$)

Figure 2. Productivity over number of unmanned shifts



On the lower end of the applications modest benefits can be achieved by a compact system and by low investment costs. There are also many standard-type solutions for the compact systems. This brings the software costs down and improves the software quality as well. If the basic software is no longer customized, but can be reproduced for many applications, the costs of single software modules will drastically decrease, or "scaled" down. Also the quality and reliability of the single modules can be "learned" through many applications, which make the system design and realization shorter and cheaper when the standard structure is re-applied.

On the upper end there are possibilities for substantial savings and benefits, although the investment costs as well as the complexity of the system are high. The potential benefits usually justify the higher investments. The second factor, which generally conforms with the use of complex systems, consists in

a real learning curve effect or economies of scale in software production. Basically this is the same "scale" and "learning" effect as already explained in the case of the compact systems, but for different reasons.

When the level which necessitates the changes in the basic systems architecture has been reached, there are many possibilities to repeat (or simply copy) the basic software modules and use the same basic modules in different interfaces and in systems co-ordination and timing. The larger the scale of the system under design, the more immediate are the benefits of software repetitiveness. This helps again with regard to the high costs of customizing. The repetitiveness of the basic modules of the software "scale" down the unit cost and also help with "learning" to improve the quality and to make the realization cheaper and shorter. However, the increasing overall complexity of the systems control and timing usually conflicts with these trends.

Figure 3a. Productivity growth (PRG) over batch size (BS)

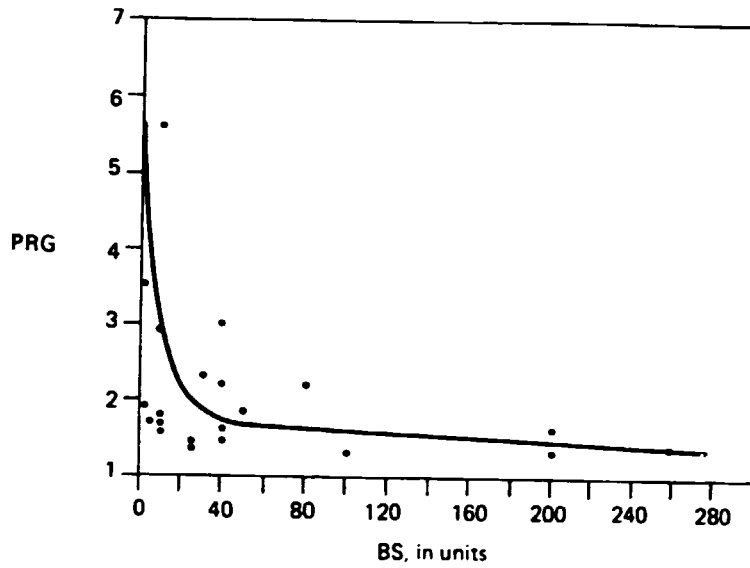


Figure 3b. Productivity growth (PRG) over technical complexity (TC)

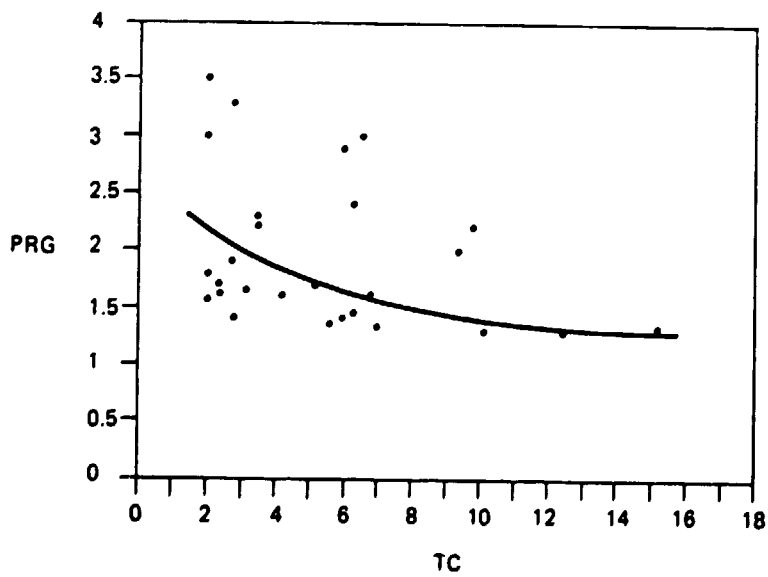
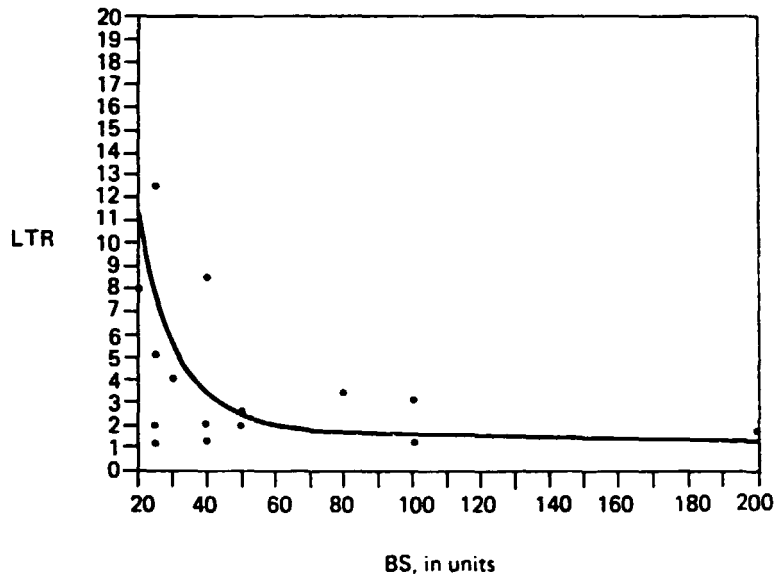


Figure 3 c Lead-time reduction (LTR) over batch size (BS)



The medium-scale systems are critical from the economic point of view. It might happen that a sophisticated systems architecture based on distributed databases and communication is needed, but the potential benefits are not high enough to justify the system investments and the system complexity is not high enough to draw the benefits from the economies of scale effects, however the software is fully customized. This remark is also consistent with the empirical data above, which show that compact, small-scale systems and very complicated, large-scale systems clearly have a shorter pay-back time than medium-scale systems. This also leads to the following conclusion: a critical technical issue for the future applications is the possibility of a module-type control structure and a transportation device, which allows for a soft extendibility of the system without drastic architectural changes.

This problem can also be called a complexity dilemma. The higher number of CNC-machines combined with a large part family usually results in such a complexity of systems co-ordination (e.g., routing, scheduling, tool management) that high

software and planning costs cannot be avoided. The only way to get the relative costs down is with a modular systems structure and standardized software modules. The benefits of standard systems structures are already clearly visible in compact systems. It is a common practice that the same basic system layout and architecture is usable in many applications, providing learning curve advantages for different applications, as explained before.

Thus, if there are no real technical breakthroughs in realizing systems controls and all-over architectures, which guarantee module-based design of systems and an easy extendibility, it is reasonable to expect that the basic diffusion paths of the flexible manufacturing systems will be of the following two types: highly efficient, high-capacity, complex systems replacing rigid transfer lines, and, on the other hand, compact, small-scale systems replacing conventional semi-manual, NC-tool-based production. The economy and applicability of the middle-range system will be highly dependent on systems control and communication software as well as on flexible transportation devices.

Thus it is obvious from the previous discussion that there are two basic implementation strategies of flexible manufacturing systems: highly efficient systems replacing transfer lines and fixed automation, or highly flexible, compact systems replacing semi-manual, small-batch production.

The starting point for the first implementation strategy is usually a fixed automation or transfer line in the mass production of a big company. The main goal is to increase flexibility, save capital and decrease the lead times as well as to cope with the changing environment and demand in the future. As FMS is replacing the highly automated lines, labor savings play only a minor role in this case.

The starting point of the second implementation strategy is usually semi-automatic or even manual production in small or medium-scale companies. The strategy is a simple capacity increase and quality improvement strategy, while sustaining the already existing flexibility.

4. FACTORS BEHIND THE RELATIVE BENEFITS

Above we have used technological factors and application characteristics to explain the differences in the empirical data on application and system cost patterns. It is reasonable to expect that these factors will also be seen as explanatory factors for different relative benefits and for independence between different indicators. For example, it can be expected that there are relationships in the statistical data between increase of production capacity, productivity growth, labor education, batch size, lead-time reduction, technical complexity and investment costs. Also, the V-shape of the relative advantage curve still needs more explanation. The pay-back time and general cost-benefit features can partly be explained by technological factors and by investment cost characteristics of the systems. However, for some indicators, such as lead-time reduction, capacity increase, etc., other explanations are needed to clarify why these also follow a V-shaped form with regard to systems complexity and investment costs.

In order to support the analyses, a special indicator describing the technical complexity (TC) of FMS has been formed. Of course, it is difficult to obtain a universal measure for complexity, reflecting the mechanical part of the systems, the software and control structure as well as the layout of the system. However, in the database there exist several indicators, which can be used to measure complexity (Tchijov *et al.* (1988a), Tchijov (1989a)).

Among them are: the number of machining centers (MC), the number of NC-machine tools (NC), the number of robots (ROB), and the types of transportation (TR), storage (ST) and inspection (INS) systems in the FMS. The last three variables were indicated as dichotomic: (1) for simple systems and (2) for sophisticated ones (Tchijov *et al.* (1988b)). The following formula was found by statistical analysis (Tchijov (1988)).

$$TC = 0.7 MC + 0.35 NC + 0.3 ROB + 0.3 TR$$

This distribution shows that 58 per cent of the cases in the FMS sample set can be treated as rather simple systems with a TC of less than four. 36 per cent of the FMS are in a middle range and their technical complexity is between 4 and 10. And only less than 6 per cent, or 18 systems, belong to a technically complex type with a TC of more than 10. According to this analysis (we should like to remind the reader again), a most typical FMS includes 2-4 machining centers, or 2-7 NC-machine tools (including MC), and 60 per cent of 64 FMS, where the use of robots was reported, have 1-3 industrial robots.

Increase of productivity and production capacity are two possible indicators, on which the above explained two main categories of systems have an impact. Thus the relative capacity increase can be expected to be higher in the case of compact systems than in the case of complex systems. It can also be expected that the labor reduction will only partly explain the productivity increase.

From the statistical data it can clearly be seen that there is a tendency for the increase of the capacity to be higher in the case of small and compact systems. This gives some evidence to the hypothesized driving forces of different applications.

It is, of course, interesting to try to explain the factors behind capacity increase. The only conclusion we can make on the statistical rate is that the capacity increase is *not necessarily* explained by productivity growth. On the other hand, those few cases for which data on the operation rate (the number of shifts in use) and unmanned operation are available show a general tendency: the higher the operation rate, the higher the capacity increase seems to be, and the higher the number of unmanned shifts, the higher the capacity increases. In general we can conclude that there are more than two (2.5) shifts in use and all the detailed cases (60) so far investigated indicate that all case study systems have gained at least one additional shift

in use (on the average 1.2). This means that the utilization rate of the production system has, on the average, increased from 50 per cent (pre-FMS) to 83 per cent (FMS).

This fact might indicate that the improvement of the *utilization rate* could be a critical factor behind capacity increase. The same tendency also exists between productivity and operation rate, as well as between productivity and the number of unmanned shifts. Thus, apart from the technological innovations, the organizational innovations play a critical role in guaranteeing an exploitation of the system's possibilities.

It is also understandable that the transformation from the semi-manual and functional production to the automated and cellular production has more potential for capacity increase or for improvement of the utilization rate than the transformation from highly automated transfer lines.

The above conclusion can be even more strongly supported. If we analyse pay-back time over operation rate and number of unmanned shifts, it can be concluded that the operation rate alone does not explain the high benefits. It is necessary to combine the use of unmanned shifts with a high operation rate to achieve economic benefits (see Figure 2).

The productivity growth is highly correlated (nearly a linear dependence) with labor reduction, lead-time reduction and set-up time reduction. This proves that *the management of time* or the unit time productivity is more critical than the classical variable costs. This is understandable in view of the high fixed capital costs (see Jaikumar (1988), Ranta *et al.* (1988c), Stalk (1988)). Also, the better the lead-time reduction, the shorter the payback time.

It is thus well understandable why FMS can be a successful strategy for capacity increase in a small-batch production, because, again through the organizational and system changes, there will be more room for lead-time reduction and a gain in capacity than in the case of transfer lines.

However, there are some very interesting relationships. Productivity growth over batch size and technological complexity is presented in Figure 3.

Figure 3a shows that a small batch size will result in a high relative increase of productivity. At first sight this seems to be contradictory to conventional thinking. Also, Figure 3c shows that a small batch size seems to result in a high lead-time reduction. Figure 3b also shows that the compact systems (low technological complexity) tend to have a higher productivity increase than highly complex systems.

How can this be explained? One explanation is that the compact systems are used to replace semi-manual production in order to increase the production capacity and to reduce the lead times of the production. The complex systems, on the other hand, are used to replace high capacity transfer lines in order to provide flexibility and capital savings. Therefore, since a small batch size is connected to small-scale compact systems, a small batch size is usually also connected to productivity growth and lead-time reduction. Thus the small and compact systems seem to keep their flexibility and complex systems are looking for flexibility. An interesting case is, however, the mid-range systems. They seem to be medium-capacity and medium-flexible systems. Furthermore, the large batch sizes are typical of these mid-range systems. This is also in agreement with above presented cost-efficiency figures and pay-back time figures.

Table 4. Economic impact of advanced production automation

	Conventional	NC functional	FMS
Case 1. Constant production capacity			
Number of machines	N	$\frac{1}{3}N$	$\frac{1}{9}N$
Production capacity	C	C	C
Price	A	$\frac{1}{2}A +$ extended design	$\frac{2}{9}A +$ extended design + extended software
Case 2. Constant number of production units			
Number of machines	N	N	N
Production capacity	C	$3C$	$(9-15) \cdot C$
Price	A	$2 \cdot A +$ extended design	$2 \cdot A +$ extended design + extended software

5. A FRAMEWORK FOR IMPLEMENTATION STRATEGIES

Facing the fact that there seem to be two classes of beneficial systems, it is worthwhile classifying some typical implementation strategies which are successful and also associate different benefits with different strategies.

We can call the basic dilemma a capacity and productivity increase problem and a complexity management problem. This fact has already been presented elsewhere (see Ranta (1988), Ranta *et al.* (1988b)), and it has also been demonstrated quite clearly by Jaikumar (1988), in his case study. We can now start with Table 4, which is a general presentation of two extreme cases.

It can be seen that if the system can be designed in such a way that capital is released or that the number of machines is decreased, then there is no need to increase the volume of production. This can typically occur in a situation when an investment for renewal is

made and this is again a typical situation occurring in bigger companies. Also, when there is a need to increase production capacity, modern production technology offers very efficient ways to do so without necessitating investment in new building and factory space. This is usually applied as one economic approach of small and medium-scale companies, as discussed above.

In other cases a remarkable increase of production capacity will result, thus necessitating a guaranteed high demand for the company's products in order to justify the investment.

In a medium-size production it can be extremely difficult to meet the above requirements because of the relatively high basic investments and the already very extensive design process.

Using the above extreme cases as a starting point, we can draft several alternative implementation strategies. Figure 4 and Table 5 give an overview of such possible candidates.

Figure 4. Capacity-flexibility problem of different strategies

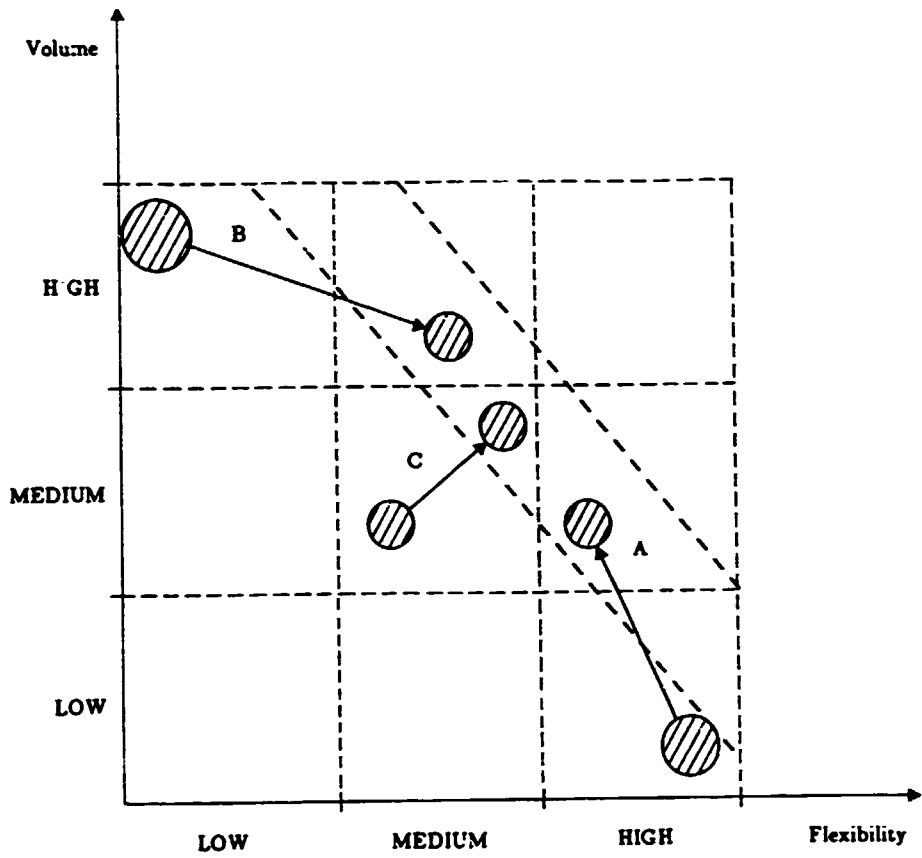


Figure 5. Product variation (PV) over technical complexity (TC)

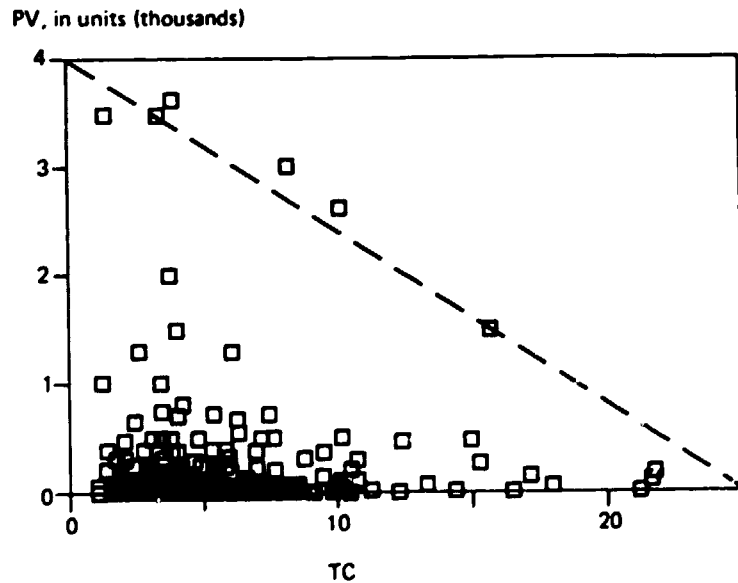


Table 5. Implementation strategies and associated benefits

	<i>Starting point</i>	<i>New system</i>	<i>Technology</i>	<i>Benefits</i>	<i>Costs</i>	<i>Risks</i>
Strategy A	<ul style="list-style-type: none"> -Small scale semimanual batch production ⇒ -Capacity C, number of machines N -Amount of fixed Capital K -Labor L 	<ul style="list-style-type: none"> -FMS, automated high flexibility -Capacity $5 \cdot C$, number of machines N -Fixed capital $2 \cdot K$ -Labor L 	<ul style="list-style-type: none"> Compact control structure - Closed Architecture 	<ul style="list-style-type: none"> -Capacity increase - capital productivity $5/2 \times$ -Labor productivity $5 \times$ -Decreased lead times and WIP -Improved quality 	<ul style="list-style-type: none"> -Increased software costs -Increased training costs -More expensive machinery 	<ul style="list-style-type: none"> -Software management -Management of change -Closed layout -Excess capacity
Strategy B	<ul style="list-style-type: none"> -High capacity dedicated automation, mass production ⇒ -Number of machines N -Amount of fixed Capital K -Labor L -Capacity C 	<ul style="list-style-type: none"> -FMS, High capacity medium flexibility -Capacity C -Number of machines $N/3$ -Labor L -Fixed capital $0.7 \cdot K$ 	<ul style="list-style-type: none"> Advanced, complex control - Open architecture 	<ul style="list-style-type: none"> -Flexibility increase -Capital productivity $1.4 \times$ -Potential for future changes -Lead time and WIP reduction 	<ul style="list-style-type: none"> -High software costs -High planning costs 	<ul style="list-style-type: none"> -Systems complexity -Skills of personnel -Low utilization rate and high fixed costs
Strategy C	<ul style="list-style-type: none"> -Conventional, functional medium scale production ⇒ -Capacity C, number of machines N, amount of Fixed capital K -Labor L 	<ul style="list-style-type: none"> -FMS, medium capacity -Capacity $1.2 \cdot C$ -Machines $N/5$ -Fixed capital $0.7 \cdot K$ -Labor $L/3$ 	<ul style="list-style-type: none"> Complex control structure - Closed or open 	<ul style="list-style-type: none"> -Capital productivity $1.75 \times$ -Labor productivity $3.5 \times$ -Quality improvements -Lead time and WIP reduction 	<ul style="list-style-type: none"> -Software costs high -Partly more efficient machinery -High planning and training costs 	<ul style="list-style-type: none"> -Management of change -Systems complexity -Skills of personnel

Strategies A and B correspond to those two substitution patterns of the old systems already described above. Strategy A can be called the capacity increasing strategy. Table 5 shows the starting point for the successful implementation of the strategy: the capacity can be increased without increasing labor costs and with a relatively slight increase of fixed capital. Thus the benefits result from the increase of both, the capital and the labor productivity. Also a clear reduction of lead times and work-in-progress should be a result of a successful implementation. However, these are only prerequisites for achieving benefits. The system has to be designed in such a way that it can meet these goals. Typically, this kind of manufacturing environment is a small batch production, where the transformation of a semi-manual process to an FMS-like process satisfies the characteristics of the implementation strategy. To be successful, however, the implementation process also has to overcome some problems which are described in Table 2 by the columns "costs" and "risks."

Usually the renewal process as well as an expanding capacity can be realized without any extra shop floor or new factory buildings. The modest increase of fixed capital is due to more efficient machinery and increased software costs, although the FMS can be regarded as a compact system.

Usually the software part of the system will also be a risk element, because software quality and reliability are critical for the system utilization rate, and because the realization as well as the maintenance require knowledge, skills and a way of thinking, which is different from the conventional system. Thus the management of the implementation is a critical factor. It is critical as a systems cost factor and as a factor of the utilization rate.

This is evident because of the multi-system nature of the manufacturing process and because of increased fixed costs necessary to keep the system in use. Therefore the *knowledge* and skills of the operators and their capability to cope with complexity, to make prognoses and diagnoses and to develop the system further are more essential than in the case of conventional manufacturing systems. Thus the whole management of change, including training and organizational issues, is critical for the success of the project.

An interesting fact is the increased capacity as such. As noted above, if this is a goal in itself, e.g. because of the growing demand, the necessary conditions can usually be met. However, there is always the

possibility of excess capacity, which, to some extent, can be an economic risk. In any case, a company has to have a strong marketing capability to avoid overcapacity. As noted by Jaikumar (1988), if there are stable markets and a stable demand for the respective products, then there will be an imbalance between supply and demand, followed by a technological renewal process and a considerable productivity increase. Then only the most efficient producers will survive.

Usually the systems architecture corresponds to a compact system. Thus the system is, to some extent, closed, and it may be difficult to extend or change it. This can be an economic risk in a changing environment.

This strategy is also an implicit labor-saving strategy, because an FMS can offer a considerable increase of production capacity without requiring new labor force or building new shop-floor space. The second subcategory is used for capital savings, e.g. to decrease work-in-progress and to decrease delivery times. This corresponds to a situation where the design flexibility is already in existence and the basic strategy is extended and enforced through modernization of the manufacturing system to guarantee rapid customizing and introduction of new products on the shop-floor level. As it is also evaluated as a capacity extension, among other alternatives, and not as a machine investment, usually also a broader evaluation of investments than ROI, or the expected cash flows, is used. The compact architecture of the system – a small number of CNC – makes it possible in this case to manage the systems complexity in spite of a large part family, i.e. a high number of product variants.

Strategy B can be called flexibility increase and future potential strategy. The economic benefits result from the increased capital productivity and the potential to make new product variations, which are usually associated with decreased lead times and work-in-progress. All these can lead to the acquisition of new market segments, due to the ability to customize products. These conditions are usually met when a transfer line is changed to an FMS-type production without losing its high capacity. Usually the technological solution is a high-capacity solution, with a sophisticated architecture and a complex control and software system. Thus the major risks come from the complex system structure itself, which is managing the software production and managing rather complicated overall planning. Because of the high price of the system, the utilization rate is even more critical than it was in the case of Strategy A.

Thus, all that was said above on training and knowledge of operators is even more evident for case B.

A typical example of the strategy is a company which is producing engines and has three fixed automation lines to manufacture 5-8 different types of cylinder heads and has an annual volume of 20,000 pieces. The company replaces those fixed automation lines by a FMS having the same annual capacity but producing all those different cylinder heads and having the theoretical flexibility potential of about 100 different heads and even some other parts. The system thus provides a considerable potential to meet the future changing markets and demands. The achieved benefits might be a decrease of the lead time from four weeks to one week, a work-in-progress reduction of 70 per cent, more rapid customizing of engines, and fewer but more expensive machines with a clearly increased software share. At first sight the system might seem to be inflexible: the part family only numbers 8. But it is flexible enough to cover the needs of the company and also to decrease potential risks of changing demands. Thus the flexibility potential is used to cope with long-term changes, such as yearly product (model) changes, or to rapidly introduce new products without changes in production. The question therefore, is one of product and production flexibilities. The small part family helps to manage the systems complexity and related software issues in spite of the high number of CNC-machines.

The third potential strategy is case C, a strategy which can be called modernization strategy. Usually the starting point is a conventional, functional layout, including the problems of lead time and work-in-progress. In this case the main benefits result from different sources: considerable lead time and work-in-progress reduction, quality improvements and a rather high increase of both labor and capital productivity. The old system as well the new system - to some extent - are medium-capacity and medium-flexibility systems. This means that the system design has to meet numerous goals just to guarantee enough benefits, as described above.

In some cases a compact systems architecture is not enough, but a rather complex control and software structure is necessary. This may be a source of techno-economic risk; it does, however, put more emphasis on planning and designing for benefits. Other sources of risk are associated with the costs and the complexity of design. The change will be rather

big. The management of this change is challenging, because a completely new way of thinking is needed in manufacturing. This necessitates again a special concern with regard to training and organizational development. Therefore the knowledge of operators and personnel is again a critical success factor.

It is furthermore interesting that there is not necessarily any capacity increase or flexibility increase associated with this strategy. All those benefits come mainly from "internal" savings. However, in some cases the product profiles and product structures have to be changed - a group technology has to be used to adapt the products to an FMS-type production. This is an additional source of economic risk.

The most successful systems seem to have a constant complexity, i.e. the product $CNC \times PV \times NT$ (CNC = number of CNC-machines in the system; PV = part family, number of variants; NT = total number of tools needed in the system) seems to be constant (see Figure 4). This means control, scheduling and related software can be managed. On the other hand, it seems nearly impossible to meet the goals of a large part family and a high number of CNC-machines (high capacity) in parallel. This is due to the exponentially increasing complexity of scheduling. The empirical data show that nearly all systems are below a certain complexity sum (straight line in Figure 5).

What was stated above conflicts, to some extent, with the conventional theory of FMS, which usually dictates that the proper use of FMS is that of a middle-range system between highly efficient transfer lines and semi-manual, highly flexible production providing medium-scale flexibility and medium-scale efficiency. According to the empirical studies above, this does not seem to be true, but those medium-scale systems are the most critical systems in economic terms. The technical and economic reasons for this fact have already been explained above. In order to be beneficial, these systems have to provide all those possible benefits usually associated with FMS: high relative labor savings, high reduction of work in progress, fixed capital savings, high reduction of delivery and lead times and increased market share.

Thus we can finally present Figure 6 as a conclusion. The unit cost and different trade-offs obey different patterns than usually believed. But these two faces of FMS seem to be evident in the light of empirical and statistical data as discussed above.

6. CONCLUSIONS

After analysing techno-economic features of flexible manufacturing systems in the world, we can draw a hypothetical conclusion that there are two broad classes of beneficial flexible manufacturing systems. This conclusion is also supported by concrete case studies. At the one end there are highly efficient and expensive systems, which are associated with capital savings and customizing in the case of fixed automation and transfer lines, and at the other end there are compact and small-scale systems, which are associated with a capacity-increasing strategy and lead time reduction. In between these two systems there is a modernization and work-in-progress reduction strategy, which can result in a complex or a compact system, depending on the starting point.

The basic typology can be explained by technological and economic factors. Because of technological limitations, there are two kinds of systems realizations, which also represent different economic barriers,

benefits and planning issues. A successful implementation is usually associated with a high utilization rate of the systems: the management of manufacturing time is critical for success. This is understandable in view of the increasing share of fixed capital, and it also causes the design, as well as the training and capabilities of the personnel, to be critical factors.

Based on the above facts, different implementation strategies can be proposed, in which benefits, systems properties and costs will meet. The implementation strategies can also explain some contradictory results obtained from the statistical data.

It can be foreseen that the technological factor will still be critical in the near future. If, due to the standardization efforts, a modular type of systems software as well as a mechanical integration technology becomes available, it will be possible to achieve step-wise implementation strategies and a wider range of beneficial systems. Then, of course, the diffusion of FMS can be wider than proposed above.

Figure 6a. Unit costs according to the conventional theory

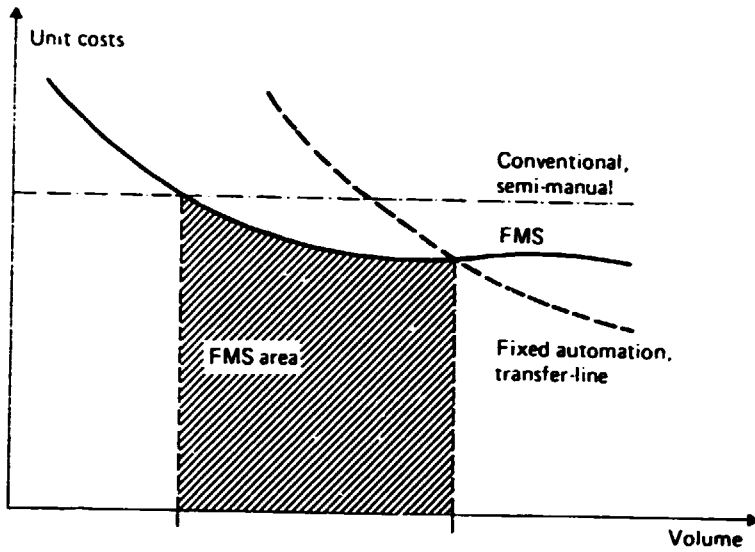
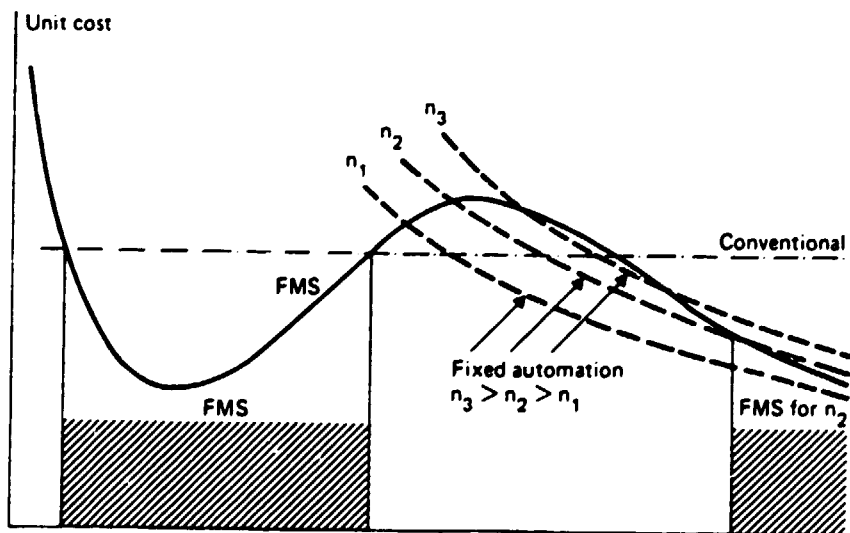


Figure 6b. Unit costs according to the revised theory (n-number of products)



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SOCIAL AND ECONOMIC ISSUES OF CIM – AN INTERNATIONAL COMPARISON

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It has become increasingly evident now that the successful adoption of CIM is by no means a purely technical question. Its success is to a great extent dependent on strategic, managerial and organizational issues as well as economic and social issues, solved in different phases of its adoption.

This contribution concentrates mainly on the analysis and results, drawn from experience, of existing flexible manufacturing systems. This analysis was started at HASA and is currently being continued at the Department of Industrial Production Management, University of Economics, Prague.

Driving Forces

The main driving forces behind the strategic decision to adopt CIM can be classified, from the economic point of view, into the following main groups.

1. Cost reduction;
2. Production increase;
3. Flexibility increase;
4. Quality increase including service.

From analysis and from other literature indications, one comes to the conclusion that CIM can attain many different goals, depending on the strategy a firm prefers. *CIM is multi-objective and the goals can be changed in the course of time.* In many cases CIM fulfills not only one but different goals. If the company strategies are divided into a defensive and an offensive one, or according to Lim (Lim, 1987) into a survival and a growth strategy, the CIM goals can be combined with these strategies. It can logically be concluded that the defensive strategy is connected mostly with rationalization investment, while the offensive strategy corresponds to strategic investment, flexibility and significant quality increase. Moreover, higher and more expansive stages of production automation and integration also aim at meeting the offensive strategies.

The hypothesis regarding the tendencies in strategy goals development is represented in Figure 1.

Figure 2 gives a survey of the preferential strategic goals in Finnish (SF) and Czechoslovak (CS) FMS. It clearly shows the combination of strategic goals, i.e. mainly flexibility (expressed in such factors as delivery time – mostly in Czechoslovak FMS), quality (expressed in delivery service – mainly in Finnish FMS) and cost reduction (expressed in labour reduction – mainly in Czechoslovak FMS, and labour and inventory reduction in Finnish FMS).

In Finnish FMS the main emphasis is on quality increase (delivery service). In Czechoslovak FMS the practical absence of quality increase as a priority strategic goal is somewhat surprising. This factor appears in only one FMS, the most sophisticated one in Czechoslovakia. This example supports our hypothesis about the tendency of strategic goals in connection with the level of automation and integration. The opposite example can be found in the case of FMS consisting of only NC-machines, where the priority goal is cost reduction (inventories and buildings), which supports our hypothesis.

The factors have different weights, which range from 1 to 5 in one system. In one case, only 1 factor of the highest (dominating) priority (4 or 5) is presented (inventory decrease). Three FMS have a combination of 2 factors, in two systems there is a combination of 3 factors, two systems show a combination of 4 factors, and one FMS presents a combination of 5 factors. In Finnish FMS, the average number of dominating factors is 2.75, and in Czechoslovak FMS the corresponding number is 3.00.

From the above one may assume that there are no substantial differences between the strategies chosen in planned and in market economy systems. One can say that the companies combine offensive and defensive strategies. Even in the most sophisticated systems, the same combination exists. But the ways of realizing the offensive strategy are different. Finnish FMS stress mostly quality and Czechoslovak FMS stress increased flexibility (for more detail see Maly, 1988).

Figure 1. Strategic goals

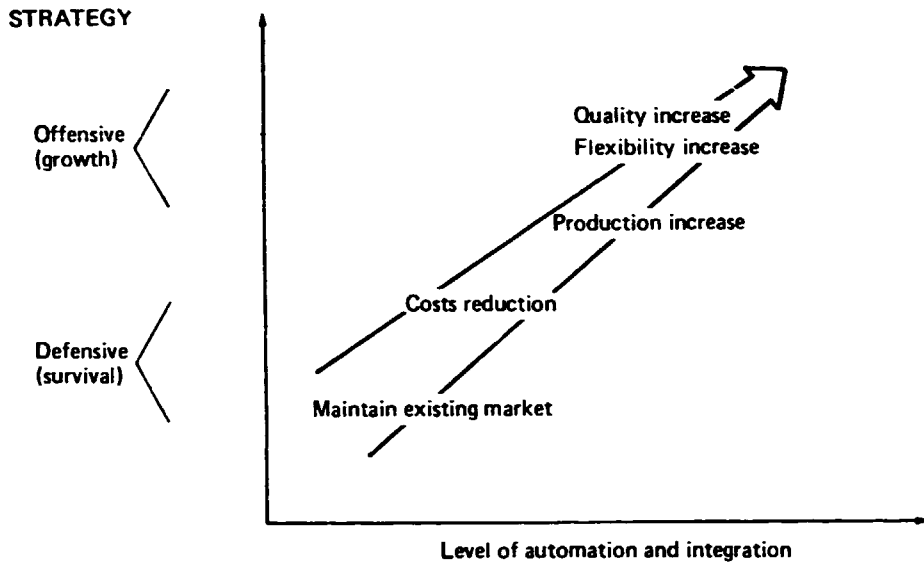
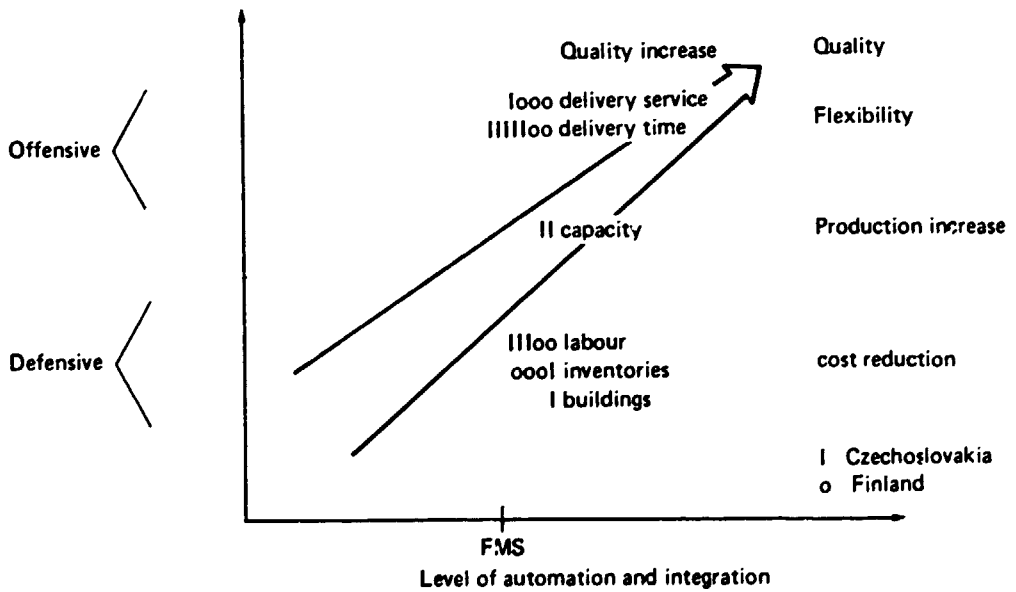


Figure 2. Strategic goals – SF-CS pilot study



Economic issues

It is evident that for a cross-country comparative analysis the main methodological problem is to specify the list of significant and comparable indicators. For this comparison, the indicators were gathered into three main groups of variables:

- Labour saving;
- Capital saving;
- Flexibility increase.

From the data collected (for more detail see Maly, 1987), one may analyse similarities and differences of economic benefits in each of the different economic systems, market and centrally planned economies. One may take into account that the percentage illustrates the comparison of real value of indicators in conventional and FMS systems in each group of countries, i.e. comparison is not of real values but of the value of changes.

The first piece of knowledge is that the statistical basis of western FMS is much richer and wider than that of the eastern FMS. From the total of 33 indicators, only 13 are available in eastern countries. This means that in the group of variables *LABOUR SAVING* one can compare 4 indicators, in the group *CAPITAL SAVING* 6 indicators and in the group of *FLEXIBILITY INCREASE* 3 indicators.

In the group of *labour saving* the results are almost the same with regard to the indicators operating rate and labour costs. The average value of the indicator labour (manufacturing) productivity increase in eastern FMS is only about 70 per cent of the value in western countries and the biggest difference is in unit costs (25 per cent of the western value).

In the group of *capital saving* almost all indicators have very similar average values. The difference is not greater than 10 per cent. Higher differences can only be observed in pay-back time (however, the eastern value of 2.2 years is only an estimate) and in throughput time (the western value amounts to 75 per cent of the eastern value).

The biggest differences can be seen in the group of *flexibility increase*. The western values are much higher (higher flexibility) than the eastern average values. The biggest difference is in batch size, where the eastern value is over 1500 per cent higher (reversed

relation!). The eastern country indicator of product variety is only 28 per cent of the western country indicator and the eastern country reduction of new product lead time as a result of FMS adoption is 40 per cent compared with 96 per cent of the western country value.

From the above-mentioned results, one can conclude that the main differences are in the group of flexibility variables, both in product flexibility and production flexibility. In production flexibility the difference is more distinctive (batch size, product variety) and these results illustrate very convincingly that the western country FMS are far more flexible than the eastern country FMS.

The main reason is probably the lower driving force of market conditions and competition, together with the strict long-term targets in the centrally planned economies, which cannot fit the real short-term consumer needs. One of the main goals of economic reforms in all eastern countries nowadays is to increase the speed of response of suppliers to consumer needs.

A graphic survey of the similarities and differences in indicators of benefits in east and west is given in Table 1.

Social issues

In the social area one can follow many indicators, characterizing the changes as a consequence of the adoption of automation, e.g. division of labour, educational level, ratio of direct-indirect workers, ratio of changes in professions and work contents, etc. This paper will take a closer look at only one social issue, the so-called technocentric or anthropocentric approach in the man-machine architecture in CIM systems, today very frequently discussed in the literature. The problem has two main angles. Some authors stress the qualitative angle and regard the technocentric approach as "technology controlling man" and the anthropocentric approach as "man controlling technology." In the first case, the technocentric approach keeps man subordinate to the system and places no higher requirements on human qualifications. The anthropocentric approach puts man in control of the system and needs the multi-skilled operator who, with a very wide, open-ended repertoire of skills, will manage the system despite unforeseen disturbances. From this angle, the Finnish and Czechoslovak FMS both tend towards the anthropocentric approach.

Table 1. East-West Comparison of Indicator Values

Indicator	E/W Value	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Labour productivity increase	W	320% (7)*																			
	E	230% (4)																			
Labour costs	W	57% (4)																			
	E	63% (9)																			
Unit costs	W	40% (1)																			
	E	10% (2)																			
Operating rate	W	20 hours (74)																			
	E	20 hours (8)																			
Number of machine tools	W	56% (35)																			
	E	57% (8)																			
Machine tools utilization	W	61% (6)																			
	E	57% (1)																			
Floor space, factory land area	W	54% (11)																			
	E	50% (2)																			
Total gross output	W	400% (2)																			
	E	375% (E)																			
Pay-back time	W	3 years 26																			
	E	2.2 years (4)																			
Throughput time	W	80% (5)																			
	E	80% (7)																			
New product lead time	W	96% (12)																			
	E	40% (3)																			
Product variety	W	157 variants (161)																			
	E	45 variants (13)																			
Batch size	W	95 pieces (29)																			
	E	1450 pieces (2)																			

* Figures in brackets mean the frequency of indicator. E = estimate.

The second, quantitative angle of this problem stems from the idea that man can be replaced by machines and control devices. The role of the system operator will be to fill the gaps with the thoroughness of a designer. Thus, one logical conclusion is that the more expansive and complicated the system, the fewer people it will need.

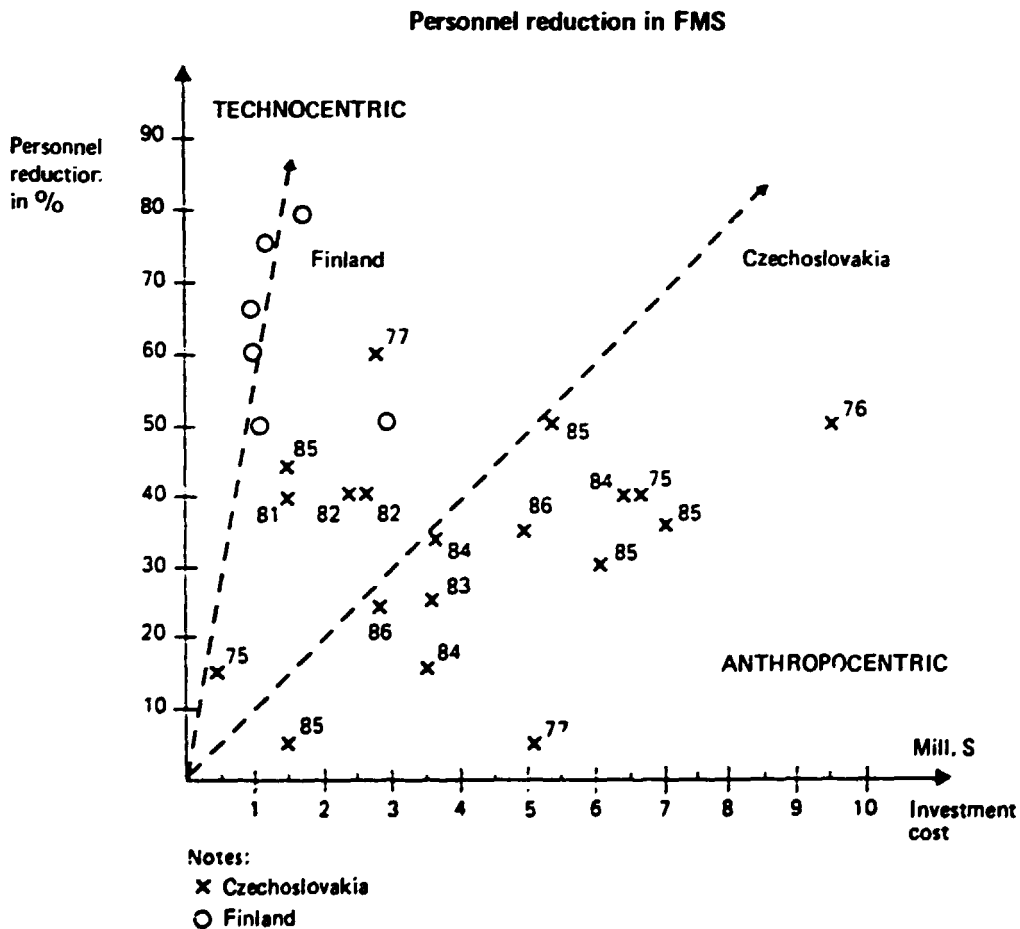
Figure 3 shows the results of 19 Czechoslovak and 6 Finnish FMS. The interconnection between personnel reduction (in per cent) and investment costs (in million US \$) is presented. On the basis of these results, one could conclude that, assuming only the second angle of the technocentric and the anthropocentric approach (personnel reduction), the Finnish FMS distinctly tend to the technocentric and the Czechoslovak FMS to the anthropocentric approach. However, another explanation of this phenomenon could be that the economic conditions

in Czechoslovakia leave little room for personnel reduction. The figures on the graph indicate the year of installation of every system, from which it becomes clear that this factor does not have any influence on this phenomenon.

Conclusion

This paper aimed at presenting decision makers with detailed information relevant to the system connections of the adoption of CIM technologies. The goal is to create and verify the hypothesis from the managerial, economic and social perspective and thus to contribute to a better understanding of the mechanisms through which CIM will influence different firms and industries. The deeper the level of understanding, the more beneficial the adoption of automation will be.

Figure 3.



Notes

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NATIONAL DIFFERENCES IN THE BUSINESS ENVIRONMENT FOR AUTOMATED MANUFACTURING

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Comparisons between United States — Japanese Business Strategies

There are significant differences between the manufacturing strategies of United States companies and other western economy firms, Japan in particular (FERDOWS). Automated manufacturing strategies in Japan are now focusing upon abilities to continue cutting production costs and to respond rapidly to product and process design changes dictated by market conditions. American and European manufacturers, on the other hand, are still playing catch up with Japanese competitors; their emphasis is upon improved quality and delivery performance, and they are still preoccupied with upgrading their manufacturing technologies.

One reason why Japanese firms manufacturing CAD/CAM equipment are in a stronger position to cut costs and respond to competitors (relative to United States and west European competitors) is because of their strong linkages forward to customer-users and their strong background linkages to their component suppliers (BARANSON-83: 17-24). United States and European firms have been relying more heavily upon mergers and acquisitions to shore up their competitive manufacturing capabilities; they are also preoccupied with the cost-profit squeeze that has resulted from rising materials and overhead costs, on the one hand, and an inability to raise prices because of intensive global competition, on the other hand. Global competition is also being driven by dramatically shortened product-life cycles that necessitate expanded efforts to redesign products and adapt process engineering to new designs and new materials.

Another essential feature of Japanese management is that it emphasizes human resource development and management as the essential ingredient of maintaining manufacturing systems, in contrast to its competitors' practices. Whereas American firms are still preoccupied with the painful and costly task of adjusting labor-management relations, the Japanese are able to concentrate their energies on adjusting work rules and broadening the range of jobs the factory worker can undertake, in order to increase the

flexibility of response of their labor force and the overall efficiency of their manufacturing operations. With much more stable and mutually reinforcing labor-management relationships, the Japanese are able to concentrate on improved just-in-time production and inventory management, which have become essential to CAM operations. By way of contrast, American firms are relying to a much more intensive degree upon the development of software embodying information data and expert systems to raise the levels of manufacturing performance. With the people and organization ingredients already in place and functioning at relatively high levels of performance, the Japanese are able to concentrate their efforts upon improved FMS and robotics. European firms are still heavily encumbered by the people-management problem, due to entrenched cultural and political factors that undermine production rationalization efforts.

If you were to compare the prevailing western enterprise approach with the prevailing practices of their more aggressive Japanese competitors regarding the design, production and marketing of a new product, you would find the following contrasting differences:

1. *Sequential versus Tandem Approach.* The Japanese firm is able to complete the innovation cycle in one-third the time or less by working in tandem both within the company and with its well integrated family of component and parts suppliers. Among Japanese firms, the product manager has an integrative role in combining the design, production and marketing functions into an integrated whole. Western firms work in sequence; product designers do not take manufacturability into adequate account and there is often insufficient regard for the details of customer usage in terms of performance and servicing characteristics.
2. *Cross-functional Training.* The Japanese are willing to invest in the cross-functional training and work assignments of their employees so that the subcultures of design, production and marketing can more effectively harmonize design features. This applies both to changes in

consumer preferences and to flexibility in manufacturing. Among western firms, manufacturing problems often emerge at a later critical stage because of inadequate involvement of manufacturing engineers at the product design phase.

3. *Forward and Backward Linkages.* Forward linkages to customers and backward linkages to suppliers are taken much more seriously by the Japanese manufacturers than by their western counterparts. Their linkages are regarded by Japanese firms as indispensable relationships in the conception and introduction of products into the market-place. Whereas most western firms plan tooling only after the product design has been frozen, Japanese firms typically release tentative designs to tool suppliers. Most American firms in particular have a low regard for the discernment and judgment of consumers. They also treat parts suppliers on an adversarial basis, rather than cultivating loyalty as an indispensable element of high-performance results. The exceptions have been firms such as Xerox that have drastically cut back the number of suppliers down to a tight-knit family of dedicated companies.
4. *Team Spirit versus Adversarial Cultures.* There is an underlying difference in "corporate cultures" values, attitudes, and social relationships which ultimately contribute to the Japanese ability to repeatedly beat American and European competitors to the market-place. Among western enterprises, there is perpetual rivalry and juxtapositioning among marketing, manufacturing and design people. For example, marketing people will resist design changes that imply re-educating the customer to a new or different mode of product utilization. There also is a fundamental lack of trust and rapport among the subcultures of marketing, production and design. What is needed is a harmonization of the subcultures, which may be achieved through cross-functional experience. In Japanese culture, there are strong pressures for individualism to give way to the collective interest. Among western societies, it is only in certain team sports or "good" wars that the collective will to win and survive is brought to bear.
5. *Incremental versus Big-Leap Changes.* Japanese companies rely upon continuing small incremental changes in response to shifts in consumer demands. The small increment approach also applies to emerging manufacturing technology opportunities related to materials, tooling, and process technology.

Needless to say there are exceptions to the above generalizations on both sides. But the fact remains that the widespread and prevailing tendencies in Japan does give their manufacturers a tremendous tactical advantage over the vast majority of western firms. The first step toward redressing Japan's comparative disadvantage would be for western firms to recognize the deep differences that exist and find culturally compatible ways to overcome the resulting disadvantages.

Experience of the Federal Republic of Germany (ICMA)

The Federal Republic of Germany machine tool manufacturers in the flexible automation field see the need to intensify contacts between users and producers and between marketing and manufacturing functions in order to be more effective in designing and building automated manufacturing equipment and systems. The widespread introduction of microelectronics has resulted in radical changes in machine tool requirements in terms of labor-saving and capital-saving characteristics. These reductions in man-hours and capital input per unit of production have been made possible, despite the increase in the unit value of automated manufacturing equipment, by the substantial increases in machine productivity derived from additional automation and the possibility of using machines on a larger number of shifts. As a result of the described shifts in the demand for automated manufacturing equipment, the volume of outside purchases from component and systems suppliers has increased, thereby necessitating the inclusion into machine systems of components, accessories and other machines which cannot be produced by a particular manufacturing company. This has added to the logistical burden of manufacturing automated equipment.

Innovation and specialization have come to be viewed as the "weapons" which, via optimization of products and systems for manufacturing them, will allow the European industry to emphasize its ability to offer customized products to match specific user requirements. In meeting these new demands by the Federal Republic of Germany (and other European) manufacturers, suppliers of flexible manufacturing systems have had to deal with the following shortcomings or difficulties:

1. *Need for specialists:* Procurement of qualified and experienced personnel is problematic, due to short supply of personnel. Personnel procured externally often are in conflict with their contractor and their employers.

2. *Computer Reliability:* Special measures are necessary against computer malfunction and for a quick restart. To overcome this, the TANDEM fail-safe system is used, which leads to a reduction of performance, but not to a stoppage of the system.
3. *Selection of Computers:* Decisions for computer technology are prone to "boomeranging." For instance, the TANDEM technology is not mass produced and only a few people are in command of this know-how. In addition, the TANDEM technology is not suitable for direct process control and needs a philosophy and software that are totally different from the IBM computers.
4. *Machining of Parts:* The reduction of setup and batch-change times is one of the most important concerns in the automation of certain parts. It is for this reason that the automation production control system initiates the new batch as soon as possible.
5. *Managing Co-ordination:* Production automation requires specialists working in segmented areas and management of overlapping tasks, which in turn have to be properly co-ordinated and integrated.
6. *Process design and organization to include man-machine-computer relations:*
 1. The rigidity of computer-aided systems demands a flexible attitude toward computer application and the unavoidable constraints of organized efforts.
 2. The logic of the computer is not adequate to the logic of man. Hence the need for understanding the reactions and behaviour of colleagues. Also information must be given free of "computer chinese."
 3. Novelty of aids such as computers, screens, and printers requires information and instruction of personnel, well in advance, in order to get people accustomed to the operating user manuals.
 4. Documentation of organizational procedures and data processing requirements in the form of reference books available on the scene are an absolute necessity.
7. *Non-availability of Sensors:* High technology, specifically "sensor technology," is needed for automated production, especially in large-scale production. Although appropriate sensors are not yet available for every process parameter, production monitoring systems are already

operational today, accounting for marked improvements in productivity and quality.

8. *Machine Utilization:* The periods in which machines are in operation are dependent upon staff's working hours, breaks stipulated by collective agreements and down time due to technical reasons, differentiating between scheduled and unanticipated down time. Optimizing machine utilization, as well as preventive maintenance, involves changing tools only during breaks.

In the face of the foregoing difficulties and in order to meet the new competitive challenges, the Federal Republic of Germany's automated equipment manufacturers have adopted the following policies and strategies:

1. *Strive for Quality of Product ("Technik")*

The Federal Republic of Germany has a very high regard for techniek leading to quality production achieved through technical competence on the factory floor.

2. *Planning for the Day after Tomorrow*

Because of the necessity of the consensus-seeking decision processes for installation of industrial plants, delays result between the time a decision is made and when it is implemented. This results in a long span of time between today's ideas and so-called "factories of the future."

3. *Long-Term Precedence over Short-Term*

To compete effectively in the future, the Federal Republic of Germany's single-mindedness as a national stereotype has to be both accurate and effective. This is achieved by focusing attention and resources on a single industry and not being distracted by greener pastures. There is no concept of the "cash cow"; the Federal Republic of Germany keeps investing back into the same business.

4. *High Quality*

In order to achieve a constantly high quality of parts, production processes are kept repetitive, and material compositions the same.

5. *Organizational Continuity*

To change and adapt the organization of the plant in accordance with the requirements of manufacturing and information technology, in such a way so as to assure the functions for the starting phase. These indispensable functions are laid down and are binding for each department in the entire organization.

East-West Comparisons (BARANSON-87: 11-25, 127-130)

In the Soviet Union as in the western economies, human and organizational factors are overriding determinants in the rate of introduction of the new automated manufacturing technologies and, even more importantly, in the results achieved in terms of increased productivity, quality and reliability of output. In the USSR, as in the United States, the basic inhibitors to the rapid and effective introduction of automation are – risk aversion and conservatism on the part of the industrial management, weak linkages between automated equipment suppliers and users and between component suppliers and equipment producers, and reluctance on the part of factory workers to accept automation (for different reasons in the United States and the USSR). Other characteristics of the Soviet "command economy" that have retarded the rate of diffusion of automation technology in the USSR are: priority allocation of production resources to military, over civilian, needs; over-ambitious production goals and "taut" economic planning; emphasis on quantitative output, rather than improved productivity and diffusion of innovation; incentives based on fulfilling production targets, rather than reducing costs, or improving product quality; and in the absence of pricing mechanisms and consumer sovereignty, failure to raise production efficiency and promote improvements in the quality and utility of consumer products and intermediary industrial products (BLAIFFER: 6-7). In the absence of consumer sovereignty and the competitive forces of a buyers market, the principal attraction of automated manufacturing technologies (and forces to drive their introduction) is lost in the "seller's market" that prevails in the USSR. A major advantage inherent in the new generations of computer-aided design and manufacturing (CAD/CAM) is *flexibility* of response to changes in consumer demands and to the competition of cheaper, better products entering the market-place.

The resistance of Soviet factory managers to the introduction of automated manufacturing systems is traceable in large part to the tautness of Soviet central planning, which in effect penalizes failure to meet production targets, inadequately rewards improved performance, and does not compensate for the added risks involved in innovation. But many of the technical difficulties that Soviet factory managers are encountering with robotic equipment are mirrored in American enterprises. In the USSR, Soviet factory managers have resisted the introduction of robotics into their factory operations because of the dislocating effects of restructuring production to fit around the

robotic equipment and coping with shortages in required ancillary equipment or "connecting systems." Frequent breakdown of robots (coupled with the dearth of maintenance personnel and replacement parts) have compounded the difficulties. The down time connected with these accommodations seriously jeopardizes meeting production quotas. More fundamentally Soviet managers have found that the introduction of robotics and related automated manufacturing equipment is difficult to do piece-system, but may even require redesign of the product to accommodate the new equipment – something especially difficult to achieve in a taut, centrally planned economy.

In its ongoing efforts to introduce robotic equipment at the factory level, Soviet ministries are better at agitating than in servicing clients. Recurrent cycles of enthusiastic campaigns generated by the planning authorities are followed by the hard crunch of trying to live with recurrent shortages of materials, components, ancillary equipment and critical support services. Often cited are deficiencies in experienced operators for automated machinery and maintenance skills and related technical support services for computer-integrated equipment. Also cited are shortages of components such as electric drive mechanisms, sensors, control devices, and computer software for robotic equipment.

The shortages characteristic of the civilian side of the Soviet economy are reinforced by the prevailing "seller's market," as distinct from the economic forces at play in the market-driven, western economies (in significantly varying degrees – highly driven in Japan, less so in the United States, and much less so in the United Kingdom, for example) (BARANSON-87: 11-17). Market forces compel enterprises in western economies to take the added risks of introducing automation in order to survive. In the absence of these market mechanisms, there is no compelling force to overcome Soviet managers risk aversion toward innovation within the Soviet system. The Soviets are by no means unique in this regard. Different varieties and degrees of risk aversion on the part of industrial management are found in western economies, where managers also respond to their respective economic environments. (BARANSON-87: 54-57, 102-105).

The conservatism on the part of Soviet factory managers is of a special variety and is traceable to structures and conditions described earlier. First and foremost, enterprise autonomy is severely constrained under the central planning system. On the supply side, Soviet factory managers manufacturing for the civilian sector must take what is supplied to them,

whether it be equipment, components or materials, and live with the deficiencies in materials and manpower available to them. On the demand side, they are not compelled to meet sovereign consumer demands and face competing producers, as they would be under competitive conditions in a market-driven economy. to decrease production costs and continuously improve product designs. For the Soviet manager, the prospect of automation is attractive only to the extent that it will help him increase his quantitative output, *without* incurring the concomitant risk, pain and penalty for failure. In a word there is no "invisible foot" that compels the Soviet enterprise manager to incur the added risk and pain of innovation in order to survive.

There are also dramatic differences in the risk and rewards to factory management related to increased productivity and improved quality of production. Profit drives the American enterprise; in the USSR the incentives to excel are moderate as compared to the penalties for failure to meet (quantitative) production targets. The foregoing instills widespread conservatism toward the high-risk that is associated with even modest changes in manufacturing methods.

The deep-seated contrasts between the planned Soviet and market-driven American economies have profound implications in the demand-pull for automated manufacturing equipment and systems. These systems require close linkages between design, engineering and production functions, and close management control over material and parts suppliers, if they are to achieve acceptable levels of proficiency. The two very different enterprise environments in the USSR and in the US engender fundamentally different evaluations by industrial managers of cost-benefit ratios and risk factors related to the introduction of automated technologies.

Another fundamental problem in the Soviet system – not entirely unique to the Soviets – is the weak linkage between research and design institutes and the production operations levels. Among the cited deficiencies are the following: designs that are not well co-ordinated, equipment that has not been pre-tested for factory operation, and ancillary equipment that is not in place. At international meetings, Soviet scientists engaged in research associated with automation and related fields such as artificial intelligence (used in programming automated equipment) are on a par with their western counterparts. It is in the area of application and utilization, including the design of prototypes that fit effectively into factory operations, where the Soviets have experienced considerable difficulties.

The Soviet approach to design engineering of military equipment responds in part to the shortages and deficiencies experienced in a command economy. This is achieved by designing down to the level of manufacturability in the industrial sector and to the operability and maintainability of products in both the military and civilian sectors. In the United States, a good portion of the high cost of defense procurement (and related national budgetary deficits) is attributable to an industrial philosophy that anything the Department of Defense envisages as a need (including the Strategic Defense Initiative systems) can be designed, and anything that the engineers design can be manufactured. The Soviet approach reverses the process and tries to tailor the design of products to meet the new customer requirements and emerging productive capabilities, both in terms of resource costs and manageability of industrial operations. The key word in Soviet military design are "operability, maintainability, and manufacturability."

The paradox of high performance in the military procurement area, contrasted with low performance in the civilian sector, can be explained in terms of the priority placed upon defense-related production over industrial output for civilian production. The seller's market that prevails in the civilian sector is completely reversed to a buyer's market, where defense procurement is involved. In the procurement of military equipment, the Soviet Defense Ministry is able to demand high performing products, insist upon quality standards and cost effectiveness, and get whatever product configurations are required. Equally important, the Defense Ministry is able to allocate essential materials, components and industrial equipment to special industrial facilities manned by the top engineering and technical skills available in the USSR. In the Soviet economy, "residual" human and physical resources are allocated to the civilian sector. In short, in the defense procurement area, there is an effective demand for the features that automated production technology can deliver – flexible response to changing demands and supplying high-performance products based upon quality and reliability 'built into the production process.

Implications of CIM for Business and Society

Business Enterprise Organization and Management

The new systems will require a profound restructuring of enterprise organization in terms of creativity and flexibility of response to change; in external linkages

(with customers and suppliers), and in internal interactions (among design, engineering, production, and marketing units). New combinations of hardware, software and database management and communication technologies will be required to facilitate dynamic co-ordination among functional units and reallocation of resources in reference to market changes and manufacturing environments. Japanese multinationals have found that there is a basic conflict between standardizing components worldwide and the necessity to establish separate centers in western Europe and North America to design and engineer products for different customer needs and market demands. One solution is to link CAD/CAM designers through a common computer network (FT-WHY).

Internal linkages are indispensable to the need to design, engineer, produce and market more complex, diverse and high-quality products in much shorter time spans and still remain competitive. Marketing is the leading link into expanded earnings and returns, but manufacturing is central to corporate strategy. Capturing higher-priced, low-volume demand niches emerge as a mainstay of comparative advantage. Externally, marketing, production and design people need to interact more intensively with customers, and production-design people need to interact more intensively with suppliers. Marketing is a key linkage into suggesting new products for the manufacturing clusters to produce. Product design people will need to be able to convert market potential into products that the in-place manufacturing complex is capable of producing. In some cases, R and D "failures" may be turned into successes by creative and aggressive marketers. A classical example of the foregoing is the yellow stick-on tabs that 3-M now markets; the R and D people had come up with a paper adhesive that would not dry, and this was turned into a new market opportunity.

The new manufacturing technologies also require direct external contacts with customers to tailor products to end-user demands and to service and assist customers in the use of increasingly complex equipment and systems. Since on-time delivery of components and parts is an integral requirement of CIM systems, nucleus plants and their vendor satellites will need to locate where transportation and communication networks provide the required market access. Another critical consideration is locating where labor is willing to accept new work rules and new factory disciplines (see below) associated with zero-defect production and flexibility in job tasks. Hence the movement in the United States to Sunbelt regions of Tennessee, the Carolinas, Arkansas and

Texas. Vendors supplying end-product plants also will have to re-organize and relocate to meet these new requirements. This implies a regrouping of product mix, model spread, and vertical integration of operations so as to become competitive operational within the framework of factories under the new CIM technologies.

Industrial firms may develop in-house capabilities or use outside firms to do the design work for them. User firms may purchase turnkey systems or custom design and integrate the various components themselves. The advantages of in-house development are cost savings, maintaining confidentiality of company's software algorithms, and adapting designs that are tailored to a particular company's needs. The disadvantages of out-sourcing lie in the design engineering problems of integrating hardware and software from different suppliers and subsequently having to service and maintain the systems. In the United States only a few companies have the in-house capabilities to design and engineer their own systems. These firms, incidentally, also service Japanese and west European clients.

CIM technology logically moves in the direction of clusters of activities that can produce bundles of products in well integrated factory facilities. Whereas it was previously necessary to have large central facilities to take advantage of economies of scale, it will now be necessary to cluster activities to achieve economies of scope. The tendency will be initially to integrate metal-shaping and machining functions and to choose vendors that can function in close co-ordination with central plant requirements for on-time delivery and strict quality control standards. Satellite facilities will be smaller replicas of central clusters in terms of FMS, robotics and CAD/CAM linkages; they will have to be closely integrated to central plant operations in order to be able to respond to successive changes in component design and production lot requirements.

The potential efficiencies of the new machining centers and totally integrated manufacturing centers lie in their abilities to respond to market changes rapidly and cost effectively. But in order to realize these potentials, it is necessary that manufacturing becomes an integrated part of overall corporate planning, and this may imply profound changes in corporate management and operational practice. CIM technologies involve substantial investment outlays and risks and require longer-term payback perspectives. As a consequence, the risk propensities of industrial managers and corporate commitment to long-term growth and technological development are critical. Also important

is the impact of government policies and regulations upon capital markets, bank lending, and corporate risk management (BARANSON-83: 6-8).

The new CIM technologies will require fewer people with higher skills at higher salaries and internal re-organizations that not only tolerate but encourage creative and innovative people who are given more discretion and autonomy to perform their tasks. The foregoing implies different policies and objectives in training, motivating, supervising, and rewarding employees for achievements. CIM technologies will have important side effects on labor force composition and on business investments. The downward trend in factory hands per unit of output will accelerate (anywhere from 30 per cent or more below previous levels). New jobs will be generated in the design and engineering, technical marketing, and customer servicing areas and in the ancillary communication and office automation (information systems) fields. Investment levels will decline per unit of output in industrial equipment, but will rise in the factory and office automation areas of computer software, communication equipment, maintenance and customer service areas, and in human resource development. Factory labor will require more advanced skills and greater flexibility in adapting to new job tasks and work rules. One of the principal reasons that Japan is in the forefront in effectively introducing factory automation lies in enterprise capabilities to manage and motivate the labor force – in contrast to less successful efforts on the part of American and west European management based on counterproductive philosophies and practices.

Adjustments in the Economy and Society (BARANSON-83: 11-25, 63-90)

The rate of introduction of factory automation, and the ultimate contribution of automated manufacturing to the productivity and competitiveness of industrial sectors, will depend to varying degrees, on the economic environment in which the industrial facilities operate. This is because investments in factory automation involve considerable risks (as profiles on General Motors and General Electric demonstrate), and therefore government, financial structures, and government relations play an important role in the financial risks business firms are willing to take. The Soviet experience clearly indicates that the economic environment is an overriding determinant. In Japan, it is the combination of the national economic environment, along with a broad-based proficiency in the management of industrial enterprises, that has given Japanese firms a competitive edge in world markets (see below).

In the United States and in western Europe, the proficiency of enterprise management is the principal determinant of a rapid and effective introduction of automated manufacturing technology, but certain elements in the economic environment act as deterrents to enterprise willingness to introduce factory innovation and implement it efficiently. In some respects, the environmental conditions prevailing in the United States and most of the west European countries are the exact opposite of what characterizes the Japanese business environment, where "vision and consensus" bring together the business, government, labor and finance communities involved in or impacting upon, the growth and expansion of factory automation. It is highly probable that the absence of vision and consensus in the United States has contributed to a reluctance on the part of American manufacturers to take the financial risks associated with introducing factory automation and has necessitated a more piecemeal approach to automation. For an extended period beginning in the late 1960s, American firms in the consumer electronic and automotive parts industry chose to move to offshore manufacture and procurement in low-wage countries, as an alternative to investments in upgrading factory automation in order to meet import competition.

A major insight that emerges from the international comparisons of factory automation efforts is that the Japanese are in the forefront of successful application on the new generation of manufacturing technologies. The ability of Japan to manage technological change in a dynamic world economy has been an outstanding feature of Japanese society in the post-war period. Contributing to this success are their philosophy and practice of industrial management and the national economic environment in which Japanese firms operate. The major elements underlying their industrial management achievements are 1) a strong reliance on long-range planning to think through and manage technological and marketing adjustments to economic change; 2) in-depth capabilities in process engineering applied to the progressive rationalization of factory automation in manageable increments; 3) a core emphasis upon the development and management of human resources as a key to successful operations; and 4) carefully structured forward linkages to customers and backward linkages to component and materials suppliers, both of which are considered essential to cost-effective production and responsiveness to customers needs and preferences. These philosophies and practices are applied both to factories in Japan and to industrial facilities located in North America and western Europe.

Japanese firms also are in the forefront of forging transnational strategic alliances with foreign enterprise partners. These strategic alliances add to the effectiveness of Japanese firms in penetrating overseas markets through the marketing, production and technology complementarities provided by foreign partners. They also provide an added competitive edge, by shortening the time frame for the run-in of manufacturing and marketing operations. (The Toyota-General Motors joint venture in California is a classical case in point). Business operations in Japan are further enhanced by distinct advantages in the Japanese national environment, as compared to prevailing government policies and economic structures in the United States and most west European economies. The two most important characteristics in the political economy of Japanese society are "vision" and "consensus" — vision to anticipate and plan for change and an intricate political and economic structure and consensus among business, government, financial and labor communities. This combination of vision and consensus gives Japanese enterprise a strong competitive edge in the continuous technological adjustments to economic change.

The combination of vision and consensus networks also are supportive of the high risks associated with investments in factory automation. The higher risk propensity in Japan is reinforced by the longer-term view of returns on investments and the reinforcement provided by financial institutions and tax structures that encourage such investments. Tax structures and consumption patterns in Japan are conducive to the high levels of personal savings, which in turn are channeled through the banking system to productive investments that include industrial rationalization and modernization. The educational system in Japan also contributes to factory automation efforts by producing the highly literate and skilled labor force that is required to design, engineer, manage, operate and maintain the new technologies. Beginning at the grade-school level, future entrants into industrial labor force are instilled with values and attitudes fundamental to the effective implementation of total

quality control and just-in-time systems associated with the factory automation. Included here are pride in workmanship and individual responsibility for quality standards.

The Japanese experience particularly demonstrates the importance of education levels in factory automation systems. The substantial increase in the quantum and complexity of production management that is inherent in factory automation requires highly skilled cadres of engineers and technicians to design, engineer, manage and maintain factory automation systems. It also requires a high degree of interdependence among trained technicians and operators that can handle computerized information interchange among design engineering, production and marketing functions. A broader spectrum of the labor force, ranging from engineer-managers to technicians and operators, requires a higher level of basic literacy in order to man the more complex and highly integrated systems associated with factory automation.

The intensified pace of technological change and the telescoping of the design-engineering production cycles imply deep-seated adjustments from traditional pre-employment education to continuing educational systems than can respond to ongoing adjustments to change. Industrial enterprises may have to take on a larger share of the continuing educational function. It is significant to note in this regard that most Japanese firms assume that new employees, on average, bring only 20 per cent of what they need to know to function within the industrial enterprise (OHMAF). In the United States, the impression is that most American firms expect that all new employees will have at least 80 per cent of the training and skills needed to perform their jobs. This accounts for corporate attitudes leading to low investments in human resources development and a general attitude that all employees are readily replaceable. This view point is generally inimical to the inherent characteristic of the new factory automation systems that rely heavily upon individual responsibility for total quality control and just-in-time systems (WSJ-EXA).

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FLEXIBLE AUTOMATION IN THE CONTEXT OF STRUCTURAL CHANGES IN A MODERN ECONOMY

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Diffusion of flexible automation installations in market and centrally planned economies

Formal indicators of the production and use of flexible automation (FA)¹ equipment – industrial robots and NC machine tools – show a similar picture of FA diffusion in the centrally planned and market economies. However, beneath the superficial resemblance there are deep and fundamental differences.

In market economies, as we know, the diffusion of new technologies generally follows an S-shaped curve. FA installations are no exception. As can be seen from the results of many empirical studies, including those of the International Institute for Applied Systems Analysis (IIASA) project on computer-integrated manufacturing (see list of references), the diffusion of basic flexible automation

equipment is following the traditional S-shaped life-cycle curve, having now completed the initial phase of slow growth.

The studies by Dosi (1984), Freeman (1987) and Perez (1983) suggest that the new technological paradigm (TP)² is now fully developed and that over the next 10 to 15 years a rapid increase is to be expected in the efficiency and diffusion of its constituent production units. Technical progress has taken on a "normal" cumulative character and, consistent with the regularity detected by Mensch (1979), i.e. shortening of the innovation cycle as each new long wave spreads, the gestation period of innovation is seen to be contracting (table 1). The diffusion of production units of the new TP in this phase is determined by demand which, as it grows in response to more effective use of the new technology, in turn promotes a further reduction in costs per unit measure of efficiency.

Table 1.

Time span of gestation period for some basic technologies of the new technological pattern

Manufacture of computers	15-20 years
Manufacture of NC machine tools	10-15 years
Manufacture of industrial robots	10-15 years
Manufacture of microprocessors	5-10 years
Manufacture of personal computers	2-3 years

¹ Seminar paper ENG/AUT/SEM 8 R.3a, originally prepared in Russian. The full text version of the paper comprises four sections, of which the last two are presented here, abridged and translated.

² The new technological paradigm (TP) is used in the context of the new information and communication technologies, based on microelectronics and digital technology. This area is identified as the impetus for the fifth so-called Kondratiev long wave upswing (economic cycles of some 50 years).

Complete formation of the new TP at the same time signifies the establishment of an environment conducive to rapid expansion of the carrier branches. This process is exactly what is now taking place in the diffusion of FA installations, which, as the empirical studies cited in the references show, have passed from a lengthy gestation period into the growth phase.

During the gestation period of FA diffusion, which lasted roughly a decade (from the second half of the 1960s to the late 1970s), sufficient industrial experience was gained and "natural" market selection was made of the most effective technologies, which were adapted to the needs and potentialities of related production units.

Thus, as the structure of economic appraisals changed with the displacement of the dominant TPs and was reflected in the sharply reduced cost of information-intensive technologies in relative terms, the scope for effective application of FA installations began to widen rapidly. FA diffusion entered the phase of "increasing yield," characterized by steady potential growth. In view of this, it is to be expected that the combined effects of training, scales of production and gradual changes in organizational and managerial institutions will be to increase the potential for FA market penetration. Over the next 15 to 20 years, rapid and sustained diffusion of flexible automation equipment is likely in various branches of production.

FA diffusion in a centrally planned economy is substantially different. Changes in the formal indicators, especially those constructed for the purpose of long-range planning, show that in the USSR, too, there has been rapid and sustained growth in the diffusion of FA installations. However, this growth is explained not so much by the increasing efficiency of FA installations as by the concern of Government departments to showcase major achievements in the manufacture and use of new technology. This was especially apparent during the campaign launched under the eleventh five-year plan for the introduction and use of robots in industry.

According to surveys conducted at that time, as well as official statistics (*Pravda*, 26 January 1986 and 18 January 1987; Volchkevich, 1987), no less than a third of the 50,000 industrial robots produced between 1981 and 1985 had not performed even one hour's work. A sample inspection made by the People's Control Committee of the USSR in 1985 showed that the annual return on introducing 600 robots, at a cost of more than 10 million roubles, was a mere 18,000 roubles (*Sotsialisticheskaya Industriya*, 16 March

1988). Here are some more recent figures: the number of industrial robots brought into service in the first three months of 1988 fell by a quarter compared with the corresponding period of the previous year (although robot production is continuing to increase), and the pay-back period for these robots is 11 years (*Izvestiya*, 9 June 1988). There is every reason to suppose that the situation will be the same in the current five-year period following mass production of expensive means of flexible automation — flexible manufacturing systems and flexible manufacturing modules. Volchkevich (1988) reports that with some FMS down-time accounts for up to a third of working time and that precision of machining is not adequate to provide ready-to-use components, which have to be finished on general-purpose machines.

No less significant is the fact that, with flexible systems, production costs are generally three to four times higher and capital productivity 12 to 15 times lower than for conventional metal-cutting machinery. In this context it is interesting to note that, as estimated by D. M. Polterovich (1987), eight times more flexible manufacturing systems and 16 to 17 times more flexible manufacturing modules are to be installed in the USSR between 1986 and 1990 than will be produced in the United States over the same period according to predictions made by American specialists.

Thus, the relatively fast diffusion of FA installations in the USSR cannot be explained by their increasing efficiency. This is not surprising, given industry's general aim to comply with formal output volume indicators and bearing in mind the current pricing system in the centrally planned economy. Combined with absence of competition and a user monopoly, this trend means that the cost of new equipment will continue to grow relative to that of the analogues it displaces at a rate estimated by Selyunin (1985) at 10 per cent per year. Hence structural changes in a centrally planned economy cannot be brought about by price changes or by the higher relative efficiency of new TP production units, as in a market economy.

Present price relationships are basically governed by the reproduction of the oldest of existing technological patterns, formed back in the industrialization period. This explains why, in the present price system (if projected on to the reproductive structure of the new technological pattern now forming), prices for fuel, energy and many types of raw and partly-processed materials, as well as labour costs, are substantially lower. At the same time, the prices for instruments, electronic equipment, high-quality raw materials and supplies and high-technology engineering goods are

higher. These deviations of prices from the socially necessary labour costs that would be consistent with an advanced reproductive structure of the economy have a negative effect on the nominal efficiency of automated production facilities, since the development of such facilities means foregoing relatively cheap and accessible economic goods and drawing more upon high-quality expensive resources whose prices are inflated. Measures of the nominal efficiency of facilities of various technological patterns are thus simply not comparable.

In a centrally planned economy, the key role in economic appraisal is played not by prices but by centrally established priorities. Thus, to evaluate the nature of diffusion of new technologies one must rely not so much on measures of their nominal efficiency as on those technical parameters which make it possible to judge the real efficiency of the motive forces of this process.

Despite the relatively large scales of production attained, automation equipment produced in the USSR is characterized by low reliability (mean time between failures of an FMS in engineering branches is often no more than a few hours, and it sometimes takes months or even years to trace all the faulty components and make the FMS fully operational), a fact which can be explained by the unsatisfactory quality of NC systems, electric drives, low-voltage apparatus, digital display devices, bearings, polymer materials and other components – many of which, furthermore, are produced in obviously inadequate quantities. The actual conditions of production of automation equipment indicate that the requisite combination of technologically interrelated production facilities has not yet been formed. Users are also not ready to operate the new technical systems effectively. High-productivity equipment is quite often introduced unsystematically (or not installed at all) and does not operate automatically. According to figures provided by Volchkevich (1987), for example, in the first half of the eleventh five-year plan period no more than half of the industrial robots produced were actually introduced. Moreover, 95 per cent of floor-type IRs (the most common category of robots in the USSR) each service one unit of equipment, i.e. replace one worker; and in one well-known case 600 IRs replaced 85 workers. Only 54 per cent of IRs operate as part of robotized complexes and the remaining 46 per cent are not integrated. Only 45 per cent of IRs operate with tool changes and the remaining 55 per cent are tooled for only one product.

The logical consequence of building up production of automation equipment without corresponding technological advances in related spheres of the economy is to produce still greater disproportions in the economic structure. Letting the production of automation equipment run ahead like this without good reason puts excessive pressure on subcontractors, who, in order to meet the growing demand, concentrate on expanding the volume of output rather than improving its quality and reliability. In their anxiety to report that they have fulfilled the major targets set by the Government on time, the producers of component parts do not bother about production costs. As a result, the price per unit of performance of automated equipment rises from one year to the next, contrary to accepted notions about the efficiency of technical systems increasing as experience is gained in their manufacture and use. According to D. Palterovich's figures (1986), fitting metal-cutting machines with NC devices increases their cost by 7-8 times, but their productivity increases only by 1.5-2 times. According to government plans, prices for automated equipment will continue to rise in the future. It is expected that by the year 2000 the price of an NC machine tool will have doubled again; thus the average price of a metal-cutting machine will have increased sixfold by comparison with 1983, but there will be a substantially smaller increase in its productivity. In the long term, the plans provide for the improvement in the consumer qualities of new equipment to be some 10 to 20 per cent greater than the increase in its price – an insignificant figure. We may note that the margin is 90 per cent in the United States and, much greater in the basic industries of the new TP.

Thus a brief analysis of the diffusion of FA installations in a centrally planned economy confirms the conclusions of empirical studies as to its ineffectiveness. This ineffectiveness is long-term in nature and is due to the institutional structure of social production in such an economy. For the time being, expansion of the production of unprofitable automation equipment is being financed out of the budget. But this means that resources are in fact being reallocated from traditional industries to boost the output of equipment that is not fully developed, with the result that production costs do not come down, but increase – a state of affairs which cannot continue indefinitely. To maintain high rates of growth with an increasing volume of unprofitable output is becoming a very expensive business, which means that costs absolutely must be brought down (see table 2.).

Table 2.

Rates of growth of production of automation equipment in the USSR

	1970-1975	1975-1980	1980-1985	
Growth in production of equipment:				
Computers	x 4	x 2.2	x 1.7	
NC machine tools	x 1.5	x 2.4	x 2	
	1970-1975	1980-1982	1982-1984	1984-1986
Robots	x 14	x 3	x 2.5	x 1.3

Note Calculated on the basis of figures from the Central Statistical Office's statistical yearbook on the economy of the USSR and reports by the CSO (which comes under the State Committee for Statistics of the Council of Ministers of the USSR) on fulfillment of the State plan for the period 1970-1985.

In the immediate future, we must expect a further decline in the rate of FA diffusion in the USSR. If the administrative command system of organizing social production is retained, the new technology will soon be operating on a basis of simple reproduction, and the introduction of FA will be confined to a narrow sphere of high-technology industries supported by State subsidies. If radical economic reforms are put through successfully and market-economy institutions are established in the USSR, the new technical pattern can be expected gradually to replace obsolete industries, and after the appropriate conditions have been established, there will be further diffusion of FA as its economic benefits become evident in practice. The conditions in question, in addition to the establishment of supporting industries and the formation of new TP technological chains, imply changes in the pricing structure, including a reduction in the prices of control devices and electronic components and a rise in the cost of energy, raw materials, environmental protection and labour. Great importance will be attached to corresponding changes in the organization of production and efforts to raise labour standards.

FA diffusion models

The intermediate position of FA equipment production as one of the carrier branches of the new TP gives rise to a number of difficulties in modelling and forecasting its development. On the one hand, that development will depend on the effectiveness of a key factor which is embodied in the equipment but produced in the motive branches. On the other hand, the diffusion of such equipment will depend on the demand for new methods of production from other sectors of the economy, which will in turn be determined by a variety of conditions, including such unknowns as social and managerial innovations.

It has to be said that the evolution of the technological structure of an economy is a highly complex, non-linear and unpredictable process influenced by a vast number of factors and by various feedbacks. The latter must, in our view, serve as the basic material for mathematical modelling of technical and economic development processes. In addition, the evolution of any technology, and even of a complex of related industries, cannot be represented in isolation. The modelling process has to be preceded by a thorough analysis of its place in the technological

structure of the economy and of its interrelations with the economic and social environment.

The formal tools for simulating the diffusion of FA installations have to be flexible enough to take account of these circumstances. In modelling this process, the approach to be adopted is, in our view, as follows: All interrelationships between the variables of the process revealing reasonably constant patterns and correlations have to be formalized and then combined in a single model with the aid of decision-taking procedures. Such procedures also lend themselves to partial formalization, given precise specifications of criteria and limitations.

Technological advances in the modern economy comprise three types of processes which are described in different ways. The first is reproduction of the traditional technologies of the previous TP, which form the environment for the diffusion of FA. They have already reached maturity in their development and their technical and economic parameters can be regarded as constant. Traditional econometric methods can be used to describe them.

Secondly, there is the evolution of new TP industries, including FA installations. As has already been said, this is an unstable and unpredictable process, and can be described by means of learning curves, production functions with disembodied scientific and technological progress and other familiar methods.

As has already been stated, FA installations fall into the category of carrier branches of the new TP. In order to model their diffusion, technological progress in the motive branches must also be taken into account. For this purpose we can use autonomous models of scientific and technological progress in the

field of electronic components and software for FA installations. For describing various non-linear types of feedback between the evolution of FA installations and scientific and technical progress in other areas of the new TP, the systems dynamics approach is highly suitable. However, to apply it entails carrying out empirical studies of direct links and feedbacks between "level" variables in the diffusion of the new TP, and evaluating the parameters of flows between them, including various time-lags, multipliers, scale and learning effects.

Thirdly, there are the processes of interaction between the new and traditional TPs, which in the present case means the replacement of traditional metal-working technologies by FA methods. Here we can use the well-known S-shaped curves. The problem is that, because of the irregular way FA diffusion proceeds and the short time-series, normal statistical methods of evaluating parameters do not give reliable results. A thorough analysis has to be carried out to determine possible saturation levels, the speed and timing of upswings, and other parameters of the displacement processes. One of the most difficult problems is to determine when an upswing is likely to occur in the displacement of traditional technologies by FA processes in various industries. For this purpose, forecasts have to be made of the diffusion of FA installations and of the decisions to be taken with regard to investment and cost-benefit assessments of alternative technologies (new and traditional).

Each of the processes examined above can be described mathematically. The problem of combining them into a single macro-economic model can be solved in various ways, the final choice of simulation devices depending on modelling requirements.

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USE OF FM-TECHNOLOGY IN THE SMALL OPEN ECONOMY – CASE STUDY FROM FINLAND

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PREFACE

This paper is based on the data collected in Finland between autumn 1987 and spring 1989. Data for analysis has been gathered with a large FMS Questionnaire, which was prepared by IIASA in co-operation with the Finnish TES program. Filling in the questionnaire in the companies using FM technology was done by the author. The method used was a guided interview. The persons interviewed were in responsible positions in production (e.g. production managers). Data were collected from eleven FM systems in eight different companies in Finland. Additional data were also obtained from four other systems in three companies. Comparative data from other countries were gathered by IIASA. The reference countries chosen were Sweden (5 cases), Austria (6 cases) and Czechoslovakia (5 cases). The author took part in the data collection in Austria.

Most of the figures presented here are based on eleven Finnish cases. Where a larger number of cases was available from Finland, it is indicated in parenthesis e.g. (n=15). The eleven Finnish cases represent 73 per cent of FM systems in that country. Five Swedish cases cover only about 13 per cent, five Czechoslovak cases about 20 per cent and 6 Austrian cases about 75 per cent of total installations in each country.

Conclusions from a large FMS data bank have been used as additional reference material (Tchijov 1989).

This work has been done as part of the Finnish TES programme (TES – Technology, Economy, Society) which is financed by the Finnish National Fund for Research and Development (SITRA).

1. DIFFUSION OF FM TECHNOLOGY IN FINLAND

Use of the system-level production technology in the Finnish metal products industry started at the beginning of the 1980s. In 1982, two systems were built by two different companies. During the next two years, the number of systems increased by one per year. These four systems were developed more or less

in-house and were installed in big diversified multi-industrial companies.

During the next two years, six systems were installed. One new phenomenon was compact turnkey systems which consisted of two machining centres, a warehouse for pallets and transportation equipment. Another new phenomenon was the growing interest of medium-size companies in flexible automation. Four systems installed in 1987-1989 were also for big companies.

More than half the profit centres where the FMS is located are of medium size. However, in nine out of eleven cases, the mother company is big. While none of the systems mentioned here is located in small companies, some flexible manufacturing units are in use in advanced small companies.

Altogether there are 15 FM systems in operation in Finland. In addition, there are six systems in research and education applications. A rough estimate predicts that there will be slightly more than twenty FMS installations at the end of 1990. The estimate is based on information about planned investments.

These systems are located in the southern and central parts of Finland, which are traditionally the most industrialized areas. So far there is only one FM system in the Helsinki area.

Altogether there are 49 numerically-controlled machine tools in the Finnish FM systems. This corresponds to less than 2 per cent of the whole population of NC-machines in Finland and to about 2.5 per cent of cutting NC-machines (drilling, milling and turning machines and machining centres). There are 31 machining centres in these systems which corresponds to about 6.0 per cent which corresponds to the whole MC population.

The total number of industrial robots in Finland is 545. Subtracting those in educational applications (69), there are 476 in production application. Thirteen of them are in FM systems, which corresponds to 2.7 per cent.

Figure 1. Accumulation of the FM systems installed in Finland between 1982 and 1989 and a rough estimate for the near future

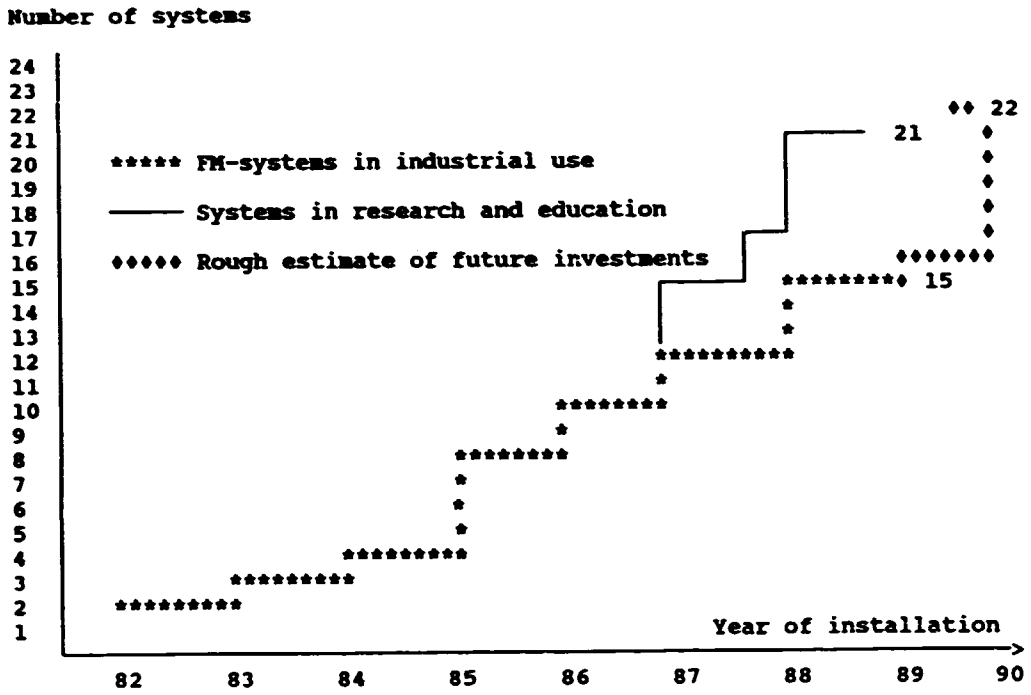
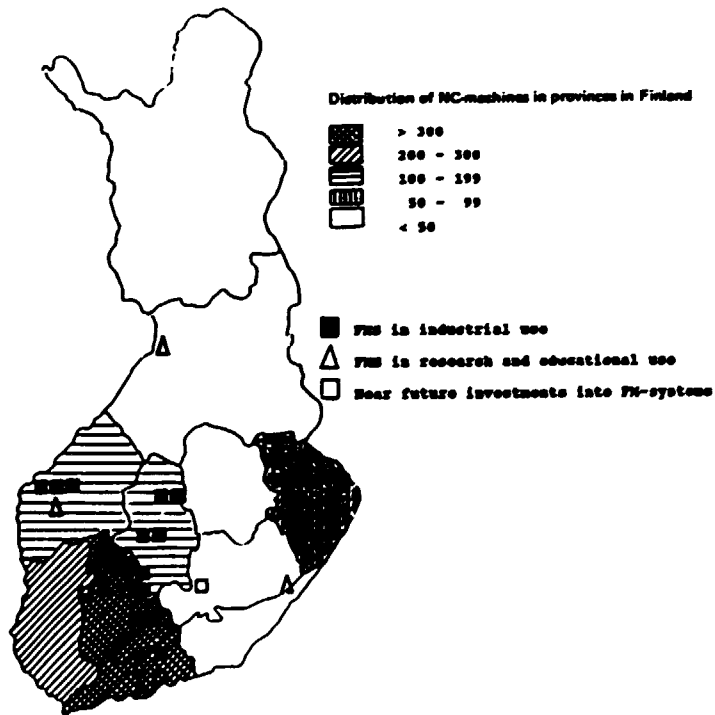


Figure 2. Regional division of installed FM systems in Finland



These figures expressed as a percentage do not give a perfect picture of the importance of FM systems, because the production capacity of a system consisting of three machines is greater than the capacity of three

stand-alone machines. However, the figures show some diffusion rates compared with single NC-machines.

Table 1.

Size scale of the Finnish companies and diffusion of FM-systems

	Number of employees	Number of cases	
		Corporation	Profit centre
Big company in Finland	over 500	9	5
Medium-size company	100-500	2	6
Small company	under 100	0	0

Profit centre = A factory or separate production unit where the FMS is located
 Corporation = The mother company of the group

2. TECHNICAL FEATURES OF THE FM SYSTEMS

A typical Finnish FM system is rather small, i.e. compact production equipment consisting of less than four NC-machines, in most cases without industrial robots integrated into the system. The magazines for tools in the machines are large. On average, more than 120 tools are reserved for each machine.

Planning and realization

The majority of the Finnish systems were planned by a system vendor. The vendor has also realized most of the systems. It is worth mentioning that in 10 out of 15 cases, the integrating parts (warehouse, control software, transportation) of the system were made in Finland. Only two systems are imported as a whole and three systems are of mixed configurations. NC-machines are mainly imported. Only two out of the 49 machines were produced in Finland.

In Sweden every case system was planned and realized by the user company. The Czechoslovak cases were mainly planned by the user and realized half by the user and half by the system vendor. All the Czechoslovak cases are of local development. All the Austrian cases were planned and realized by the system vendor. None of the system vendors for Austrian cases is Austrian. This is peculiar, because there are system vendors in Austria, but for some reason they have only export references.

Machining functions

Most of the Finnish systems produce prismatic parts. Only two systems are for rotational parts and two systems produce both prismatic and rotational parts. None of the systems is used in sheet metal applications. A couple of sheet metal FMS are now in the investment phase in Finland.

The machining functions of the 11 Finnish systems are divided as shown in the table below.

Table 2.

Distribution of machining functions in the eleven Finnish FM systems

Machining functions	
Drilling	10
Milling	10
Turning	5
Thread cutting	4
Grinding	2
Boring	1
Other functions	
Washing	7
Deburring	2
Heat Treatment	1

Almost two thirds of the machines in the systems are machine centers. Other machines used are lathes, grinding machines, sawing machines and milling machines. As mentioned before, there are only a few industrial robots in these systems. Altogether seven robots are integrated into the systems. Two of them are in deburring and five are in material handling application.

Transportation, warehousing

In all but three FM systems the internal transportation is based on pallets. On average, there are 53 pallets in each system. That is more than in the Swedish and Austrian cases, although they have more machines per system. In most cases pallets are stored in a high storage (pallet stacking). A high storage is usually, however, only two or three shelves

high to avoid the extra safety devices required by strict elevator regulations.

Transportation inside the warehouse is done by a stacker crane which also loads and unloads the machines. Only one system of the 11 participating in this research uses automated guided vehicle (AGV) as a transportation device.

Parts, products

The average machining time for parts or part pallets is about one hour. This shows that the parts machined in the systems are rather complex and that simple small parts are fixed on group fixtures. On average, the size of a part family is 134 parts. Typical parts produced in the systems are gearboxes, gear axles, flywheels for diesel engines, cylinder heads for diesel engines and hydraulic parts.

Materials

The most usual raw material is cast iron. Six of the systems use only cast iron as raw material, one uses only steel. Two of the systems use both cast and steel and two of the systems use also aluminium and brass. Materials are critical for smooth unmanned operation. Many disturbances occurring during night shifts are caused by difficult materials and wrong cutting parameters. Cast iron is the easiest material for unmanned operations.

The end-products of parts made in fifteen Finnish FM systems are shown in the table below.

Table 3.

End-products of the parts machined in the Finnish FM systems

Machines	5
Diesel engine	4
Axles	3
Machine tools	1
Transportation vehicles	1
Instruments	1

Figure 3. An example of common FMS configuration in Finland (Valmet FASD)

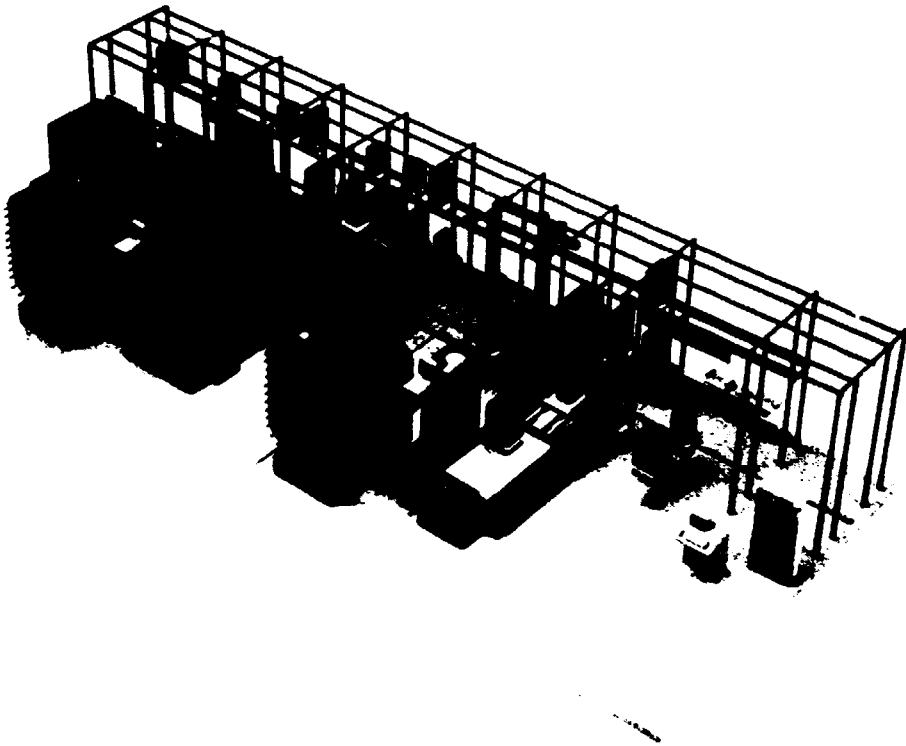
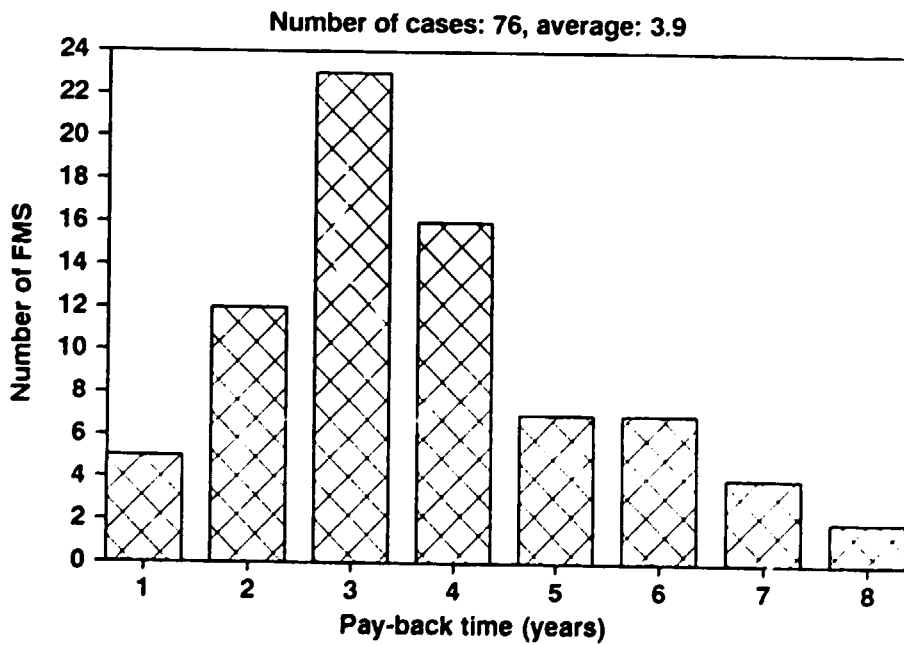


Figure 4. FMS distribution over pay-back time



Source: (Tchijov, 1989).

3. OPERATION OF THE FM SYSTEMS

Finnish FM systems are not only planned for a large part family and a small batch size but also operated according to these goals. The average number of parts the systems produce is 134 ($n=15$) which is a little more than the average planned part family (129). The smallest part family consists of 11 parts and the largest of more than 300 ($n=15$). Two Czechoslovak cases have a part family of more than the average planned part family (129). The smallest part family consists of 11 parts and the largest of more than 300 ($n=15$). Two Czechoslovak cases have a part family of more than 1000 different parts.

The average batch size is as low as 8.8. Three systems are operated with one part batch size. The highest batch size is about 40 parts. One reason for this is certainly the high diffusion rate of JIT production (JIT – just-in-time) among these user companies. The average batch size varies considerably among the three countries compared. Among the Swedish cases there are some serving the automobile industry which partly explains the large average batch size.

The correct use of an FM system is essential for gaining the expected benefits. "Don't buy a sports car if you are afraid of high speed." Realizing that is one success factor of Finnish installations. Of course there is still a lot to do to improve the operation, e.g. improving utilization rate.

- Case:

Operation of one of the case companies is based on the production of the series of one product. The company makes about 5000 different end-products from five basic modules. The five modules each have 10-35 different variations by size, shape and material. The whole production is organized to support a continuous flow of material in one-part batches. The FM systems also support this. Even if there were orders of e.g. 20 identical products, the production control system would break down the order into single parts. Actually the capacity of the whole production would collapse if there were a large order for the same product, because the pallets are tailored for specific parts.

Most of the FM systems in Finland are operated in three shifts. The average shift rate is 2.7, while it is 2.8 in Sweden, 3.0 in Austria and 2.1 in Czechoslovakia. Maximum unmanned time is on average 11.2 hours, which is much more than in the other cases. Only two Finnish systems use no unmanned night shifts. Only one of the Austrian

systems is operated unmanned. One reason for this could be the lower Austrian salary levels compared with Sweden and Finland. There could also be some cultural reasons behind this phenomenon.

4. ECONOMIC FEATURES OF FINNISH SYSTEMS AND COMPARISON WITH SOME RELEVANT COUNTRIES

Most of the Finnish FM systems seem to be economically quite successful. Unfortunately there is a lack of information concerning ROI and IRR figures (ROI – return on investment, IRR – internal rate of return), which are the most typical parameters of profitability. Information of pay-back times (which describe the financial effects of the investment better than actual profitability) is however available. On average, the pay-back time is three years, which is rather short compared with Austria and Czechoslovakia. Although it should be noticed that Finnish systems are not only smaller by number of machines but also by size of investment. International data show mostly longer pay-back times (Figure 4). It should be mentioned that the 76 cases covered in the figure include 13 Finnish cases. When comparing the size of investment per number of machine tools, it may be seen that the Swedish systems are most expensive per machine and the Czechoslovak are the cheapest.

One of the most important reasons for FMS investment is the aim to reduce capital tied to the inventories. That has also been the aim of JIT production and OPT production (OPT – optimized production technology). According to the cases examined, Finnish systems have on average reduced inventories 80 per cent and work in process 75 per cent. Swedish systems have also reduced these parameters considerably. This indicator of technical development is of course connected with a starting point. But when one looks at the decrease in per cent it is quite reliable. The large FMS data bank gives the average per cent for inventories and WIP reduction (WIP-work in progress) as 64 per cent.

The other important reason for investment is to save one expensive labour force and to replace it with automatic functions. Our cases show that even when the average absolute reduction of the labour force is quite small (because the FM systems are small compared with those in these countries), the relative labour saving is almost the same in Finland, Sweden and Austria – about 53 per cent. The large data bank gives a higher average percentage figure (77 per cent) which could be because there are some large FM

systems (almost unmanned factories) included in that data bank.

5. HINDERING AND ACCELERATING FACTORS FOR THE DIFFUSION OF FM TECHNOLOGY

The following aspects were raised when factors accelerating diffusion of FM technology were discussed:

- Technical:
 - know-how of NC technology
 - earlier experience of FM technology
 - earlier experience of unmanned production
 - construction changes in product
- starting with JIT philosophy
- Economical:
 - need to increase profitability
 - need to decrease unit costs
- Marketing:
 - need to raise capacity
 - investment as a reference
- Organizational:
 - lack of skilled workers
- Strategic:
 - strategic decision to invest in system technology

Table 4.

Average technical indicators of FM systems in Finland, Sweden, Austria and Czechoslovakia.

COUNTRIES	SF	S	A	Czechoslovakia
NUMBER OF CASES	11	5	6	5
Number of NC-machines	3.3	5.8	4.16	13.8
Number of robots	0.64	1.6	0.83	0.6
Number of tools per machine	124	59	80	66
Total number of tools	339	347	459	87
Number of pallets	53	40	28	-
Number of pallets per machine	16	6.9	6.7	-
Size of part family	134	20	103*	1338
Average batch size	9	1063	439	151
Average set up time, (minutes)	8	62	-	-
Cutting time per pallet, (minutes)	53	41	20	-
Throughout time of prod. (h)	47	37	-	-
Type of part produced: (%)				
prismatic	71	60	60	20
rotational	29	20	20	60
sheet metal	0	0	20	20

* Sheet metal case has been excluded because of irrelevant comparison.

The most important reason for accelerating the diffusion of FM technology is earlier experience with NC technology and unmanned production in general. The natural reason for diffusion is improving productivity. Some companies have made strategic decisions to invest only in system technology. The following factors hindering diffusion were mentioned:

- Technological:
 - lack of technical support from vendors
 - lack of CIM knowledge at every level of the company
 - vendors do not have practical references
 - the old products do not fit automated production
 - components for automation are too unreliable
 - too many different parts for FMS
 - quality of the electric current too low for computers

- Organizational:
 - difficulties in finding CIM experienced people
 - adoption of new production philosophy takes a lot of time
- Marketing:
 - difficulties in finding vendor
 - vendors have difficulties in fulfilling what they have promised

As can be seen, the problems run from philosophy to the quality of electric power. The pioneers have faced most difficulties concerning lack of vendors and unreliable system components. Many of the case companies seem to expect too much from the vendors. It was a surprise that none of the companies mentioned lack of capital or too high investment as a hindering factor. Also, none of them mentioned unsatisfactory investment calculation methods as a barrier. There seems to be more lack of know-how than money.

Table 5.

Average economic indicators of FMS in Finland, Sweden, Austria and Czechoslovakia.

COUNTRIES	SF	S	A	Czechoslovakia
NUMBER OF CASES	11	5	6	5
Size of investment,(US\$)	1.8	5.1	2.2	5.5
Pay-back time,(Y)	3.0	-	5.3*	5.2
Change of stocks	-80%	-77%	-25%	+5%
Change of WIP	-75%	-76%	-43%	-15%
Labour savings, absolute numb.	6.9	17.8	14.5	-
Labour savings, relative (%)	52.3	56.8	53.5	39.0
Change of unit cost, (%)	-7.5	-25	-	-15
Max. unmanned time	11.2	5 h	1.3	5.6
OTHER INDICATORS				
Average installation year	1985.6	1982.8	1986.5	1982.6
Export rate of production	60.6	62	80	46
Investment per machines (US\$)	0.54	0.88	0.52	0.39

6. TYPICAL USER COMPANY

As shown in Table 1, most of the Finnish FM systems are installed in big metal product companies which have a worldwide market area. The export rate of the products made in FMS is much higher (61 per cent) than the average in the metal product industry (46 per cent).

A typical characteristic of the enterprises using FM technology is that they are more or less pioneers in developing production with other means e.g. JIT philosophy, group technology, cell-based production, zero inventories production. Another common feature is long experience with NC-technology and the use of unmanned production with single NC-machines (FMU - flexible manufacturing unit), in some companies several years.

FM technology is also relevant to small companies. None of the small companies has so far invested in

system-level FM technology. One reason for this is the lack of fixed product structure or strong own products. They cannot invest in a production system in which the parts are fixed on rather expensive pallets and fixtures if they do not know what they will produce next month.

The fifth figure shows that the complexity of the FM systems has a correlation to FM products of the same company. The more complex system components (sensors, robots, machine tools, control equipment, system programs and FMSs) the company is delivering the more advanced (complex) production systems it uses in its own production. The two cases in the low right corner can be explained as reference and R and D cases for the system vendor. Companies which do not have any system products themselves tend to invest in compact turnkey systems. Ten out of fifteen cases are in companies which also have some system components as a product.

Figure 5.

Correlation between the complexity of the FM technology used in the Finnish companies and the level of FM technology components as a product for the same company or corporation

COMPLEXITY OF FM-TECHNOLOGY IN PRODUCTION

Complex (big) FM-system

Medium FM-system

Compact (small) FM-system

		◆ ◆	◆ ◆
	◆	◆ ◆ ◆	
	◆ ◆ ◆ ◆	◆	◆ ◆

No system products

Component vendor

System vendor

FM-TECHNOLOGY AS A PRODUCT FOR USER COMPANY

Note: (◆) indicates fifteen different case FM-systems

Notes

Books and publications

Haywood Bill, Bessant John, "The Swedish Approach to the Use of Flexible Manufacturing Systems". Innovation research Group Occasional Paper No 3, Brighton Polytechnic, 1987

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Ollus Martin, Mieskonen Jari, "Bases for Flexibility in a Small Country: Some Issues of the Finnish TES-programme: Trends and Impacts of Computer-Integrated Manufacturing". *Ranta Jukka* (Ed.), Proceedings of the Second IIASA Annual Workshop on Computer Integrated Manufacturing: Future Trends and Impacts and The IIASA Workshop on Technological Factors in the Diffusion of CIM Technology, 355-377, Laxenburg 1989

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Other material

- 11 Finnish cases in IIASA Questionnaire form
- 4 other Finnish cases based on articles in professional magazines published in Finland and on informal discussions with company representatives
- 5 Swedish cases in IIASA Questionnaire form
- 6 Austrian cases in IIASA Questionnaire form
- 5 Czechoslovak cases in IIASA Questionnaire form

PART THREE

ORGANIZATIONAL AND MANAGERIAL ASPECTS OF

IMPLEMENTING CIM

PREREQUISITES FOR IMPLEMENTING CIM — MOVING TOWARDS CIM IN JAPAN

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1. INTRODUCTION

The Japanese manufacturing technology is based on the integration of high quality and low manufacturing cost in the time horizon. The reason why it is efficient to integrate those targets in the time horizon is because the superiority of a company depends not only on monetary matters but also on "the practice policy" i.e., to plan quickly and to put it into practice quickly, to look at the whole production from the viewpoint of time, to practice plans with the best timing and to minimize the turn-around time. In Japan CIM is expected to play a key role in quickly developing, producing and distributing products in order to gain a further competitive edge.

This paper first reviews economic environments surrounding "manufacture." The second section presents some comparisons between Japan and the West on CIM concepts and approaches. The third section reports on the current status of CIM implementation in Japan. The fourth section deals with CIM in large-volume production, in which Japan seems to continue to be ahead of the rest of the world, stresses the importance of quality assurance and maintenance and points out the necessity of developing suitable interfaces among computers, machines, products/workpieces and operators for the success of CIM. The last section presents three examples of CIM which have proved to be very useful in Japan.

2. ECONOMIC ENVIRONMENTS SURROUNDING "MANUFACTURE"

2.1 Trend of supply and demand relation

In the current mature economic climate, market demand is highly variable.

Figure 1 shows a conceptual relationship between demand and supply from the time before the first oil crisis to the present. During the high growth period before the first oil crisis, there was ample demand in the market and various products were developed, produced and sold mainly on the initiative of the manufacturer. However, all markets eventually become saturated, and evidence of market saturation began to appear after the first oil crisis, as shown in figure 2.

2.2 Diversification theory

There is a theory in economics about the effect of diversification on sales (1). Figure 3 illustrates this theory. In this graph, curve S_1 shows the sales volume over time of a given product. If this product could be produced with many variations in such a way as to meet every kind of need, then sales could possibly be increased to level S_3 . Likewise, if there is a product that sells at level S_2 , sales could be increased to level S_4 with increased variations.

2.3 Growing need for products matching the individual person's circumstances, personality and tastes.

In the saturated market, manufacturing companies were forced to face intensified competition. In order to maintain and hopefully to increase sales, they tried to create a new market. For instance, in the case of consumer durables, once it was a "must" to have, say, one air conditioner in each house, but then the manufacturers succeeded in creating the feeling that each room needed an air conditioner.

Figure 1. Trend of supply and demand relation

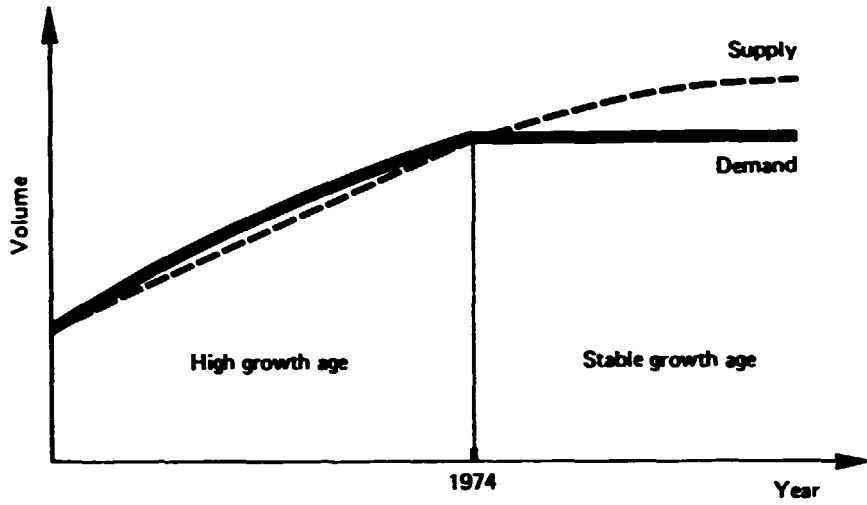


Figure 2. Transition of ownership ratio of consumer durables in Japan

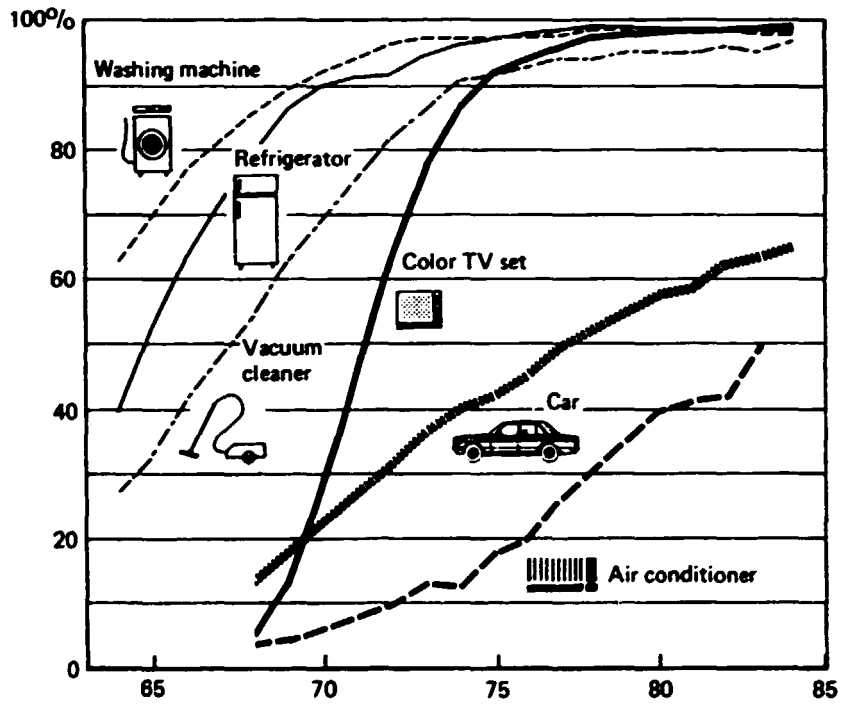


Figure 3. Diversification theory

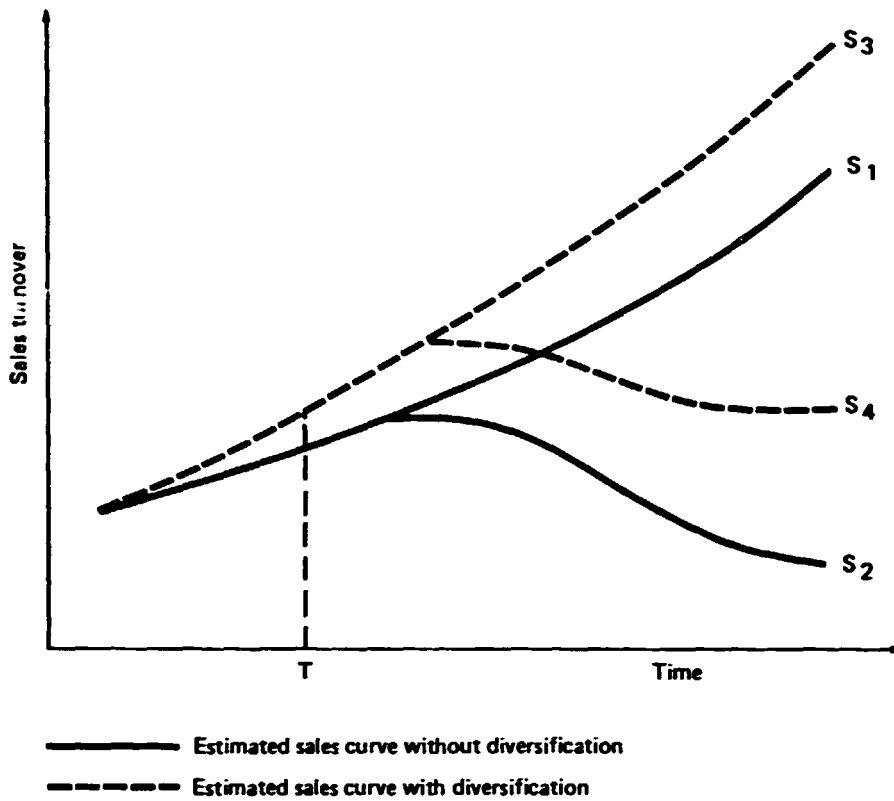
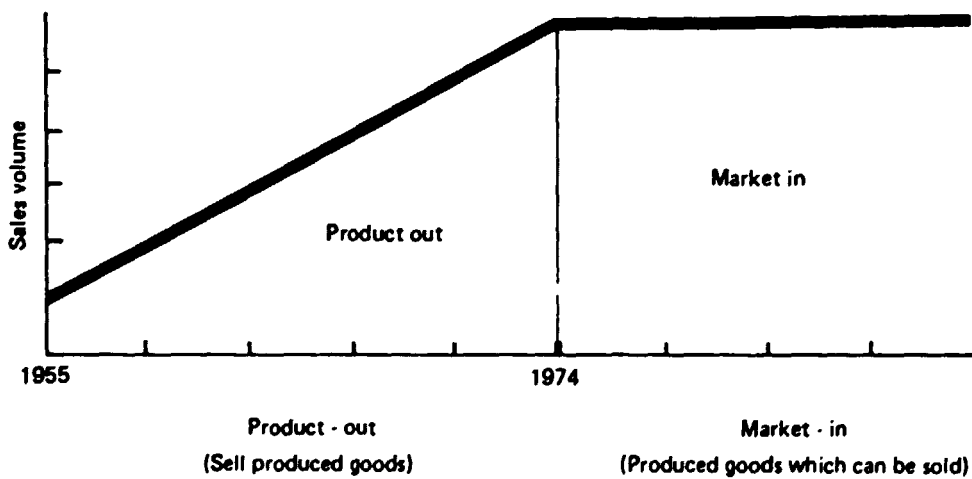


Figure 4. Economic environment



However, every room has a different capacity, space and wall colour. To put an air conditioner on the wall, on the ceiling or on the floor depending on the condition of the room, different kinds of units must be provided to fit the different needs. As the standard of living has improved, consumers who have become more affluent have willingly accepted such manufacturer's endeavours. As a matter of course, there has been a growing need for products matching individual persons' circumstances, personality and tastes.

If manufacturers sell only their main products, they are liable to lose their market share. In order to meet the diversity of customers' needs, various types of products must be produced. This tendency will become more intensified in the future. Thus, after the first oil crisis, products have come to be developed in consideration of the needs of the consumer. Therefore, the period before the oil crisis is called the "Era of Product Out" and after the oil crisis, the "Era of Market In," as shown in figure 4.

2.4 Product life cycle

Figure 5 illustrates graphically product life-cycles during the 1970s and 1980s. In the 1970s, product life-cycles were relatively longer. But product life-cycles have become increasingly shorter with multiple variations, because of new demand creating activities based on the policy of built-in obsolescence by manufacturers. In part, these activities have been supported by recent technical innovation. This trend is expected to increase markedly. Accordingly, when formulating a new production system, we must think of, first, the production volume, secondly, the number of variations and thirdly, the product life-cycle. Depending on those figures, we then have to develop a suitable production system.

2.5 Three most unfavourable conditions influencing manufacturing

We face three most unfavourable conditions to manufacturing, which are: diversified demand, great difficulty of forecasting demand, and shorter product life-cycles, as shown in figure 6.

Table 1 summarizes the problems generated by those conditions and the major issues to be considered.

With the conventional manufacturing system and production control method, it is becoming almost impossible for the manufacturer to cope with the three most unfavourable conditions to manufacturing.

2.6 Competitive factors in the market

What mainly counts as competitive factors in the market for manufacturing companies are:

- Price
- Quality including services
- Delivery date

In what order these items count depends heavily on the product. It is normally the case that when a customer wants to buy a certain product from a company, he wants to place his order with specifications at the latest possible day and that once he has made a decision, he wants to have it delivered immediately or on a certain fixed date. If he has to wait for a long time until he gets it, most probably he will lose his desire to buy it. If he finds a similar product made by another company, if the price and quality are almost the same, and if that product can be delivered much faster, he may buy it. Therefore, delivery dates are surely a very important factor for the company to be competitive.

2.7 Two solutions flexible enough to meet customers' demand

To meet customers' demand, the company can take the following two steps:

1. To keep a very high stock of finished goods.

Then, whatever demand comes, there is no danger of losing the customer since the company can meet the demand immediately. This solution is very attractive for the company since it enables the company to have stable production.

In fact, in the West there are many companies which employed or are still employing this solution. But, in such companies it often happens that they do not have the very items customers want although they have a high stock of finished goods, and that the customers have to wait for a long time until they get them.

The drawbacks of this solution are:

- Tied up capital in the finished stock can be dangerously high.
- Some of the finished stock may become dead stock because the total demand is limited and because the product life-cycles are getting shorter and shorter.

Figure 5. Product life-cycles during the 1970s and 1980s

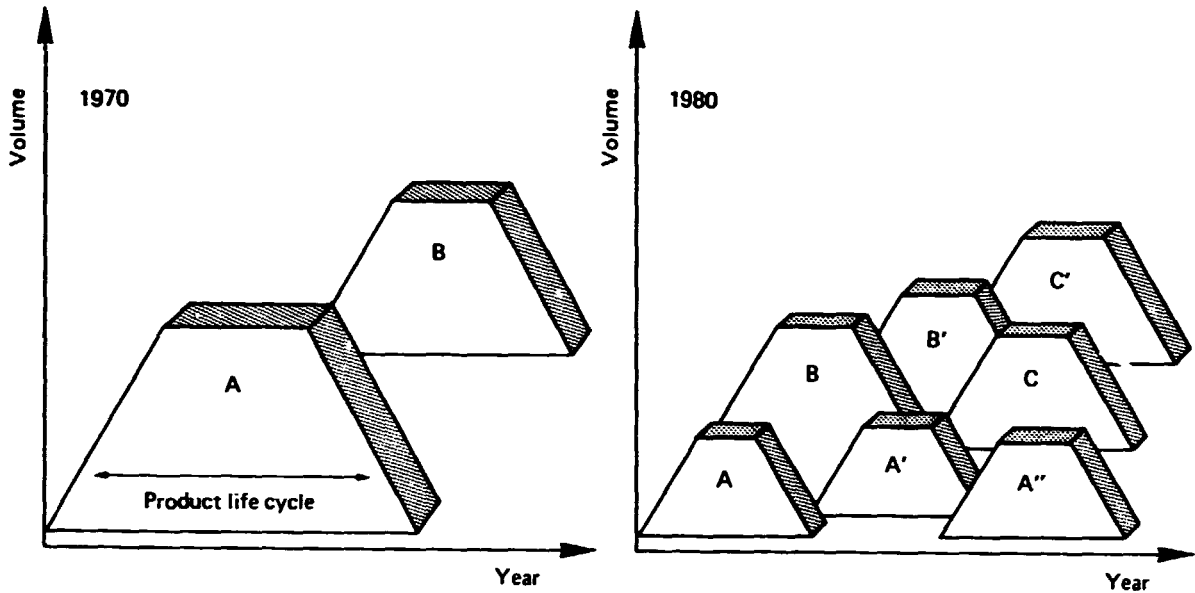


Figure 6. Market situations before and after the first oil crisis

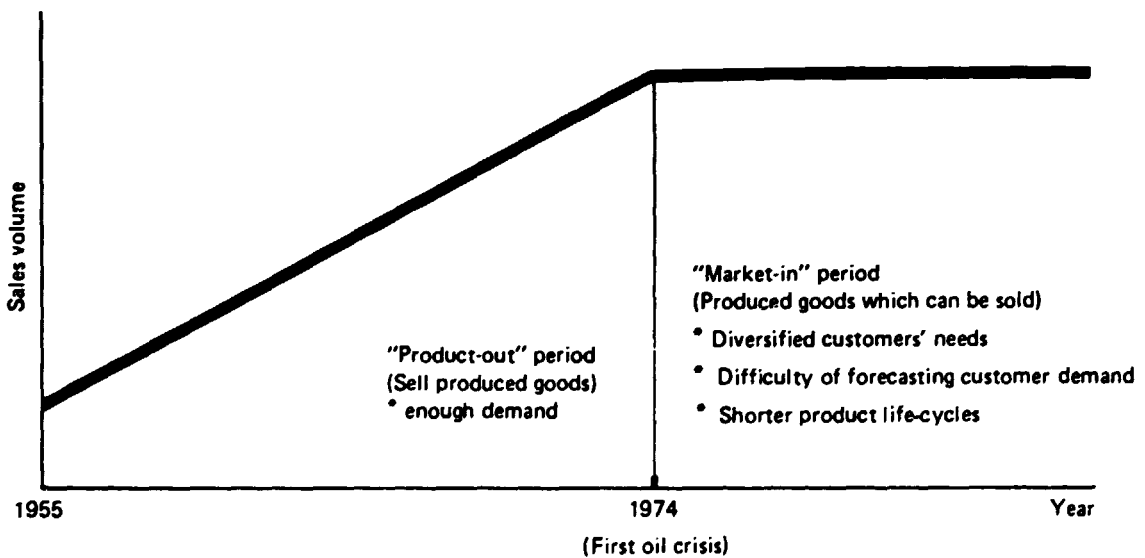



Table 1. Problems generated by three difficult conditions

Unfavorable conditions	Problems in production	Major issues to be considered
Change in demands	<ul style="list-style-type: none"> • Decrease in efficiency of personnel and facilities • More complex control 	<ul style="list-style-type: none"> • Flexibility • Lower degree of manning • Built-in quality at the process • High investment efficiency • High space utilization • Rapid capability at the start of production • Production mix • Less maintenance cost <div style="text-align: center; margin-top: 20px;">  CIM </div>
Diversification	<ul style="list-style-type: none"> • Decrease in efficiency of personnel and facilities • Lower quality • Many changes in types • Increase in part space • More complex control 	
Model change	<ul style="list-style-type: none"> • Increase in investment of new facilities • Increase in rebuilding costs of old facilities • Increase of idle facilities • Increase of changing time from one type to the next • Decrease in investment efficiency 	
New product	<ul style="list-style-type: none"> • Facility introduction to cope with the start of production • Increase in investment of new facilities • Increase in personnel • Increase in the plant space 	

- Retailers, wholesalers and manufacturers have in many cases only limited space for keeping inventory. Thus, it is very difficult for them to store all the stock.

For these reasons, this does not seem the right solution.

2. To have very short lead times to replenish the stock of finished goods. Then, whatever demand comes, it can easily be met. This is surely the right solution.

One function of inventory is to act as a buffer between sales and production and between production and purchasing. In other words, it separates the sales function and the purchasing function from the production function and enables them to function independently. The mass production and mass distribution system was made possible thanks to this buffering function of inventory, as shown in figure 7(a). But the present mature and diversified market has made this solution unfeasible. Diversification is liable to involve waste caused by the imbalance between production and sales activities. More precisely, waste caused by excessive production of products and waste not in demand caused by losing sales opportunities because of the shortage of demanded products. Thus, if the production system cannot cope with the market needs quickly enough, obviously shortage of products and excessive inventory results. This will be followed by a decrease of sales and the loss of the company's reputation.

Thus, it has become very important to be able to provide customers with the products meeting their demands at the right time and at reasonable prices, in other words, to implement "just-in-time" manufacturing and "just-in-time" delivery. To meet the demand of just-in-time manufacturing and delivery, the Japanese have found as a solution the shortening of lead-times. If lead-times are short enough, any demand can be met whatever it is and redundant stock can be eliminated. Few stock can be accepted between sales and production and between production and purchasing. In principle, with few stock, production must confront directly the diversified and unforeseen market, as shown in figure 7(b). This means that only minimizing manufacturing cost is not a sufficient criterion to operate the manufacturing system. A new element – flexibility – has become a crucial concern for operating the manufacturing system.

2.8 Vital elements to meet market demand on time

The following are the major elements required to meet market demand right on time:

1. Investigation of market demand
2. Flexible production
3. Purchasing of the necessary materials just in time
4. Integration of sales, production, purchasing and distribution functions

In other words, the competitive power of the manufacturing company increasingly depends on the speed of obtaining market information. The longer the time required for obtaining the information on market demand, the higher the stock level and the bigger the risk of manufacturing products not in demand, leading to lost sales due to shortage of demanded products. Competitive power also depends on the speed of procuring the necessary materials, of manufacturing the right products in the right quantity and of distributing them to the right place at the right time and at the right cost. In Japan, CIM is expected to play a key role in these processes – from market investigation to customer delivery.

Owing to progress in microelectronics, data base management and networking, it has become feasible to implement CIM in the following ways:

1. Software : speed up of information processing by computers, central control information and autonomous information control in the local areas
2. Hardware : flexible manufacturing facilities
3. Production management : synchronization of the flow of products and the flow of information.

3. CIM IN JAPAN

Table 2 presents some comparisons between Japanese strengths and Western strengths in production.

Owing to those different strengths, there are obviously differences between Japan and the West regarding CIM concepts and approaches.

One feature of Japanese CIM is that CIM tends to be understood in a broader sense. It may mean Computer Integrated Management involving various processes from market investigation to customer delivery. CIM is often understood in a narrower sense in the West, limiting its application to manufacturing (2)

Figure 7. Production must confront directly the diversified and unforeseen market

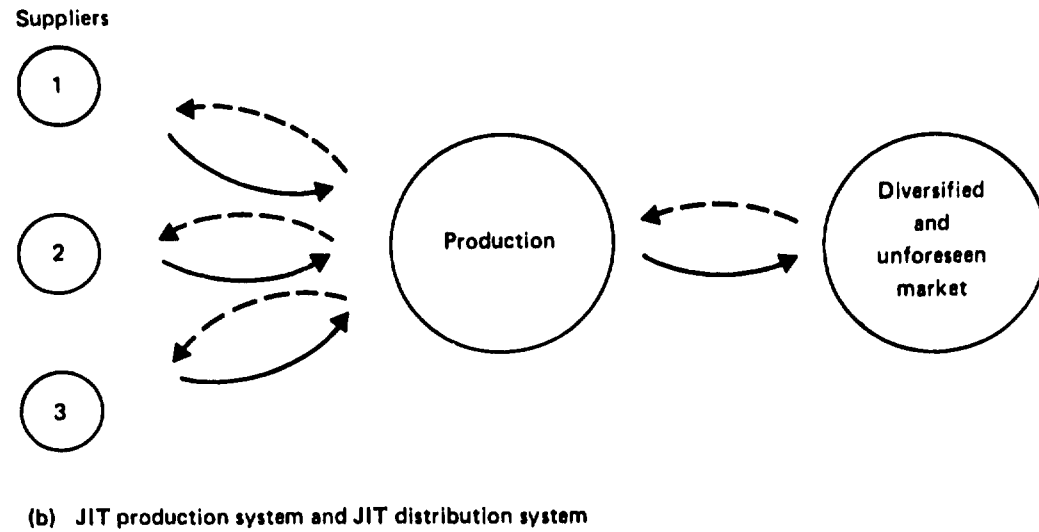
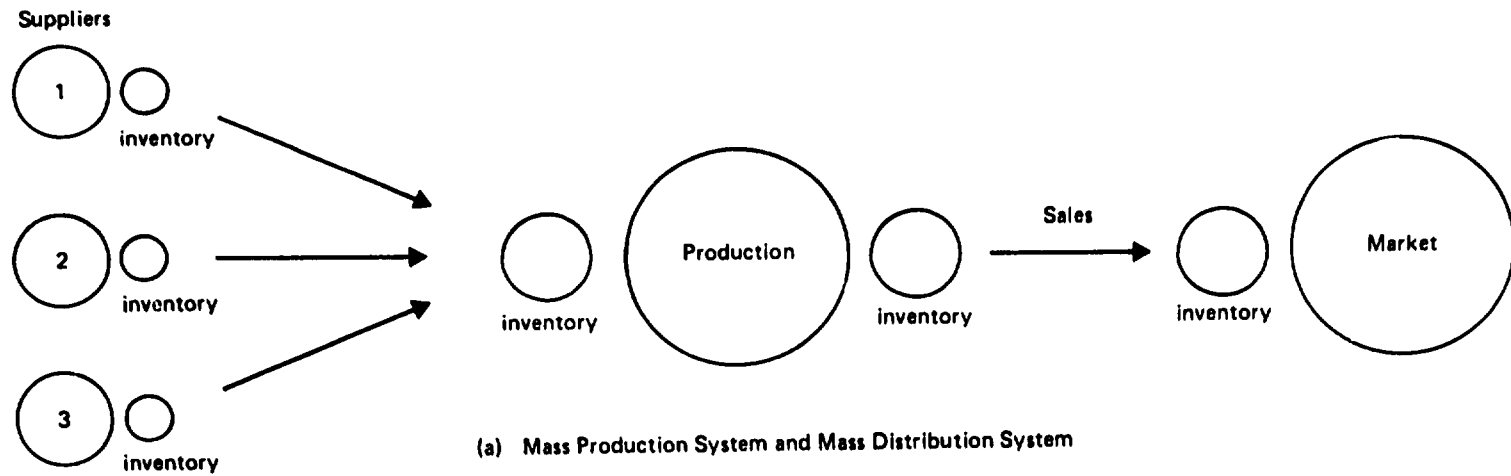


Table 2.

Some comparisons between Japanese strengths and western strengths

Japanese strengths	Western strengths
1. Applied R & D	Basic research
2. Standardized, mass volume	Customization
3. Process and production technology	Innovative product development
4. Manufacturing	New product design
5. Generalization	Specialization
6. Hardware	Software
7. Practical approach	Theoretical approach
8. Incremental improvements	Breakthroughs and inventions
9. Performance	Function
10. Quality assurance	New functions

CIM is understood in Japan to mean the application of information technology to all aspects of manufacturing, but when it comes to the precise definition of CIM, there has been no consensus yet in Japan. Many people discuss CIM from different aspects of CIM and confusion often occurs because of the lack of a precise definition of CIM.

From the lesson of the failure of MIS (Management Information System), CIM is assumed to take a hierarchical, decentralized, autonomous and co-operative form with the standardization of interfaces among system components. Figure 8 illustrates autonomous and co-operative aspects of CIM, while figure 9 shows hierarchical and decentralized aspects of CIM.

The configurations of CIM would depend on the characteristics of products to be produced (manufacturing volumes, the numbers of variants, product life-cycles, the sizes and weights of the products, the number of parts that constitute the products, etc.) and also the state of the company (the size of the company, the available human resources, the relationships with its customers and suppliers, etc.). Even in cases of comparatively similar companies, the CIM of one company would not be the same as that of another. In other words, there is no ready-made CIM. Each manufacturing company must develop its own customized CIM. The technologies of CIM are partly well known, but they are still evolving. Thus, CIM would require long-term commitment and strong leadership of top management.

4. CURRENT STATUS OF CIM IMPLEMENTATION IN JAPAN

In order to cope with the current mature economic climate which generates three unfavourable conditions, diversified demand, greater difficulty of forecasting demand and shorter product life cycles, Japanese advanced manufacturing companies have introduced step by step various tools such as NC machines, MC, FMS, robots, automatic warehouses, AGVs, etc., and recently FA. FA makes it possible to rationalize its direct labour which covers only a portion of the total manufacturing cost. Among those Japanese manufacturing companies who could afford to implement FA, the direct labour cost covers, roughly speaking, only about 7 per cent of the total manufacturing cost. The major parts of the cost are the material cost (more than 60 per cent) and the overheads (more than 20 per cent). Such companies have found that FA has obviously a limit in rationalizing manufacturing and are now moving toward CIM. It must be noted that such companies are just a handful of the first-class manufacturers. There are many companies who are not yet ready at all to introduce CIM.

JMA (Japan Management Association) conducted a survey on the "Current Status of CIM in Japan" in 1988 by sending questionnaires to 800 Japanese manufacturing companies listed on the first sections of the Tokyo stock exchanges. Of the 800 companies, 277 companies answered. The definition of CIM used by JMA is "a highly efficient and flexible integrated system covering various functions from order receipt to delivery by unifying all the information flows with

the assistance of computer technology." This section presents some of the survey results.

4.1 Situation of CIM implementation (figure 10)

About 30 per cent of the companies claim that they have partly implemented CIM.

4.2 Who decides to introduce CIM (figure 11)

It is well known that Japanese manufacturing companies improve the level of automation from the bottom to the top, step by step. But when it comes to CIM, top management needs to take the initiative in carrying out the implementation of CIM. This is because CIM requires long-term commitment, radical changes, strategic investments and internal "order."

4.3 Areas of CIM implementation (figure 12)

There are many manufacturing companies who consider it useful to implement CIM in the areas of manufacturing, order, receipt, production design and production preparations, material procurement, sales and distribution.

It is worth noting that the Japanese manufacturing companies are not expecting CIM to play such an important role in K and D.

4.4 Purposes of implementing CIM (figure 13)

The purposes of CIM implementation in Japan are mainly to shorten lead-times, to automate small-batch production, to strengthen co-operation between production and sales, to lower the overheads and to reduce work-in-progress.

Figure 8. Autonomous and co-operative aspects of CIM

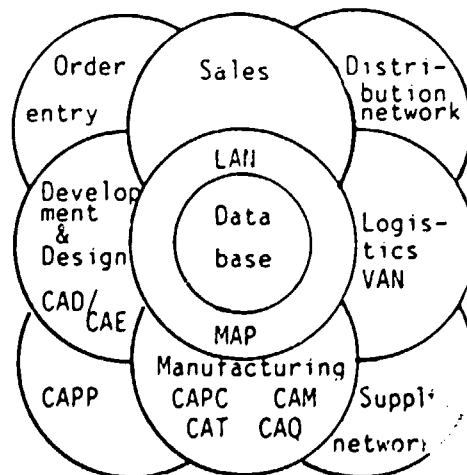
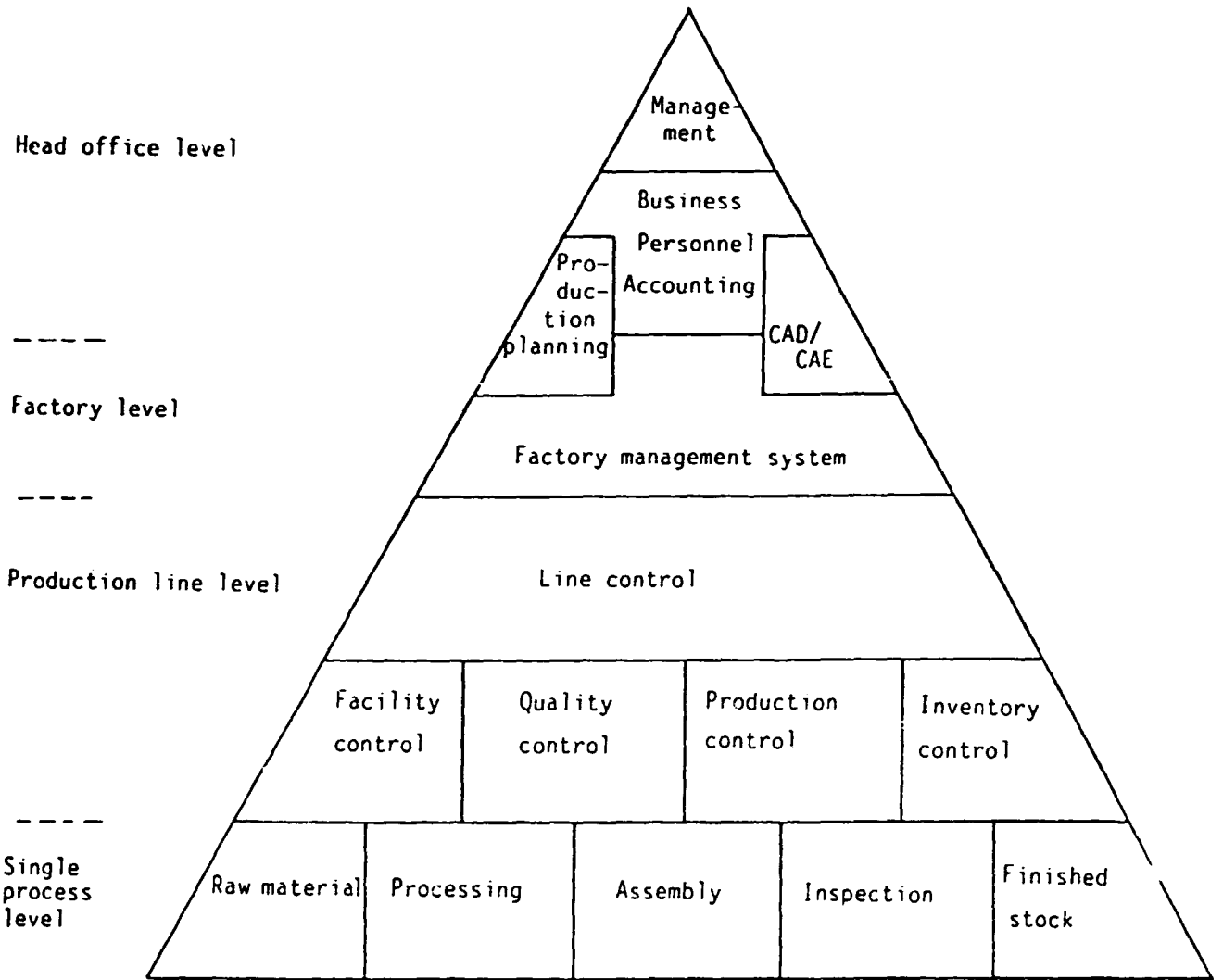


Figure 9. Hierarchical and decentralized aspects of CIM



4.5 Changes in job content by CIM implementation (figure 14)

The major changes in job content are standardization of operational sequences and rules and unification of receiving information at each function.

4.6 Problems encountered in the process of implementing CIM (figure 15)

The major problems to implement CIM are insufficient personnel to develop in-house software, insufficient staff who have strategic views on CIM implementation and difficulty in evaluating investment.

Figure 10. Situations of CIM implementation

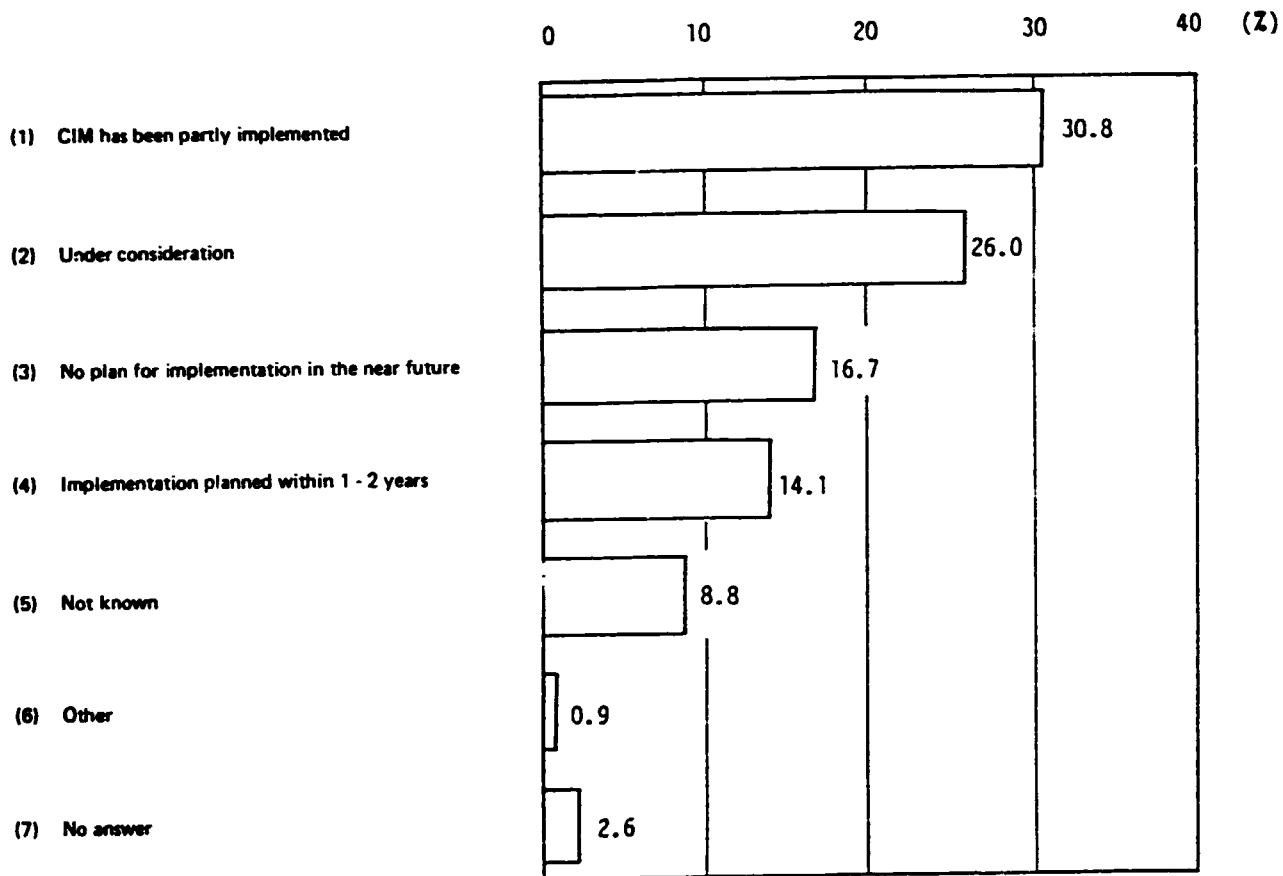


Figure 11. Who decides to introduce CIM?
(Source: JMA 1988)

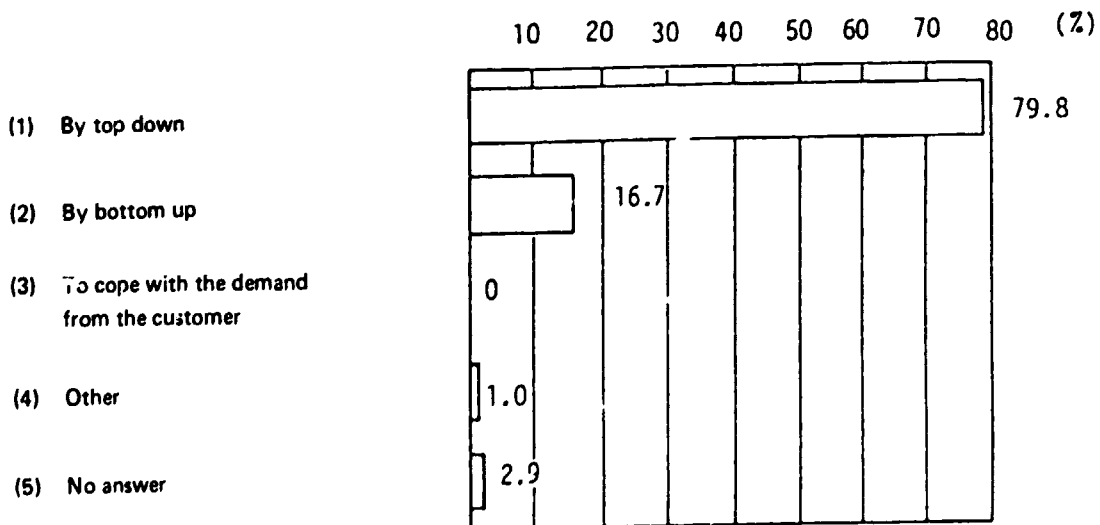


Figure 12. Areas of CIM implementation
(Source: JMA 1988)

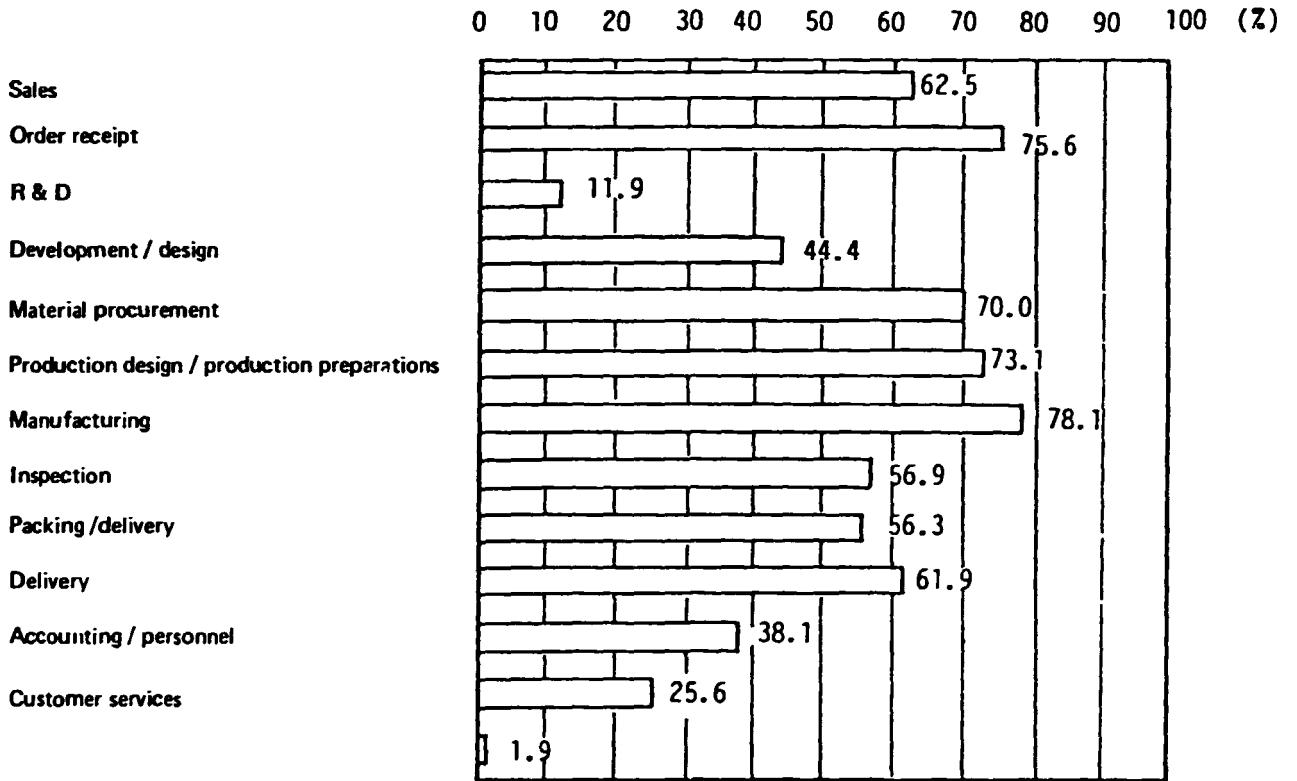


Figure 13. Purposes of implementing CIM

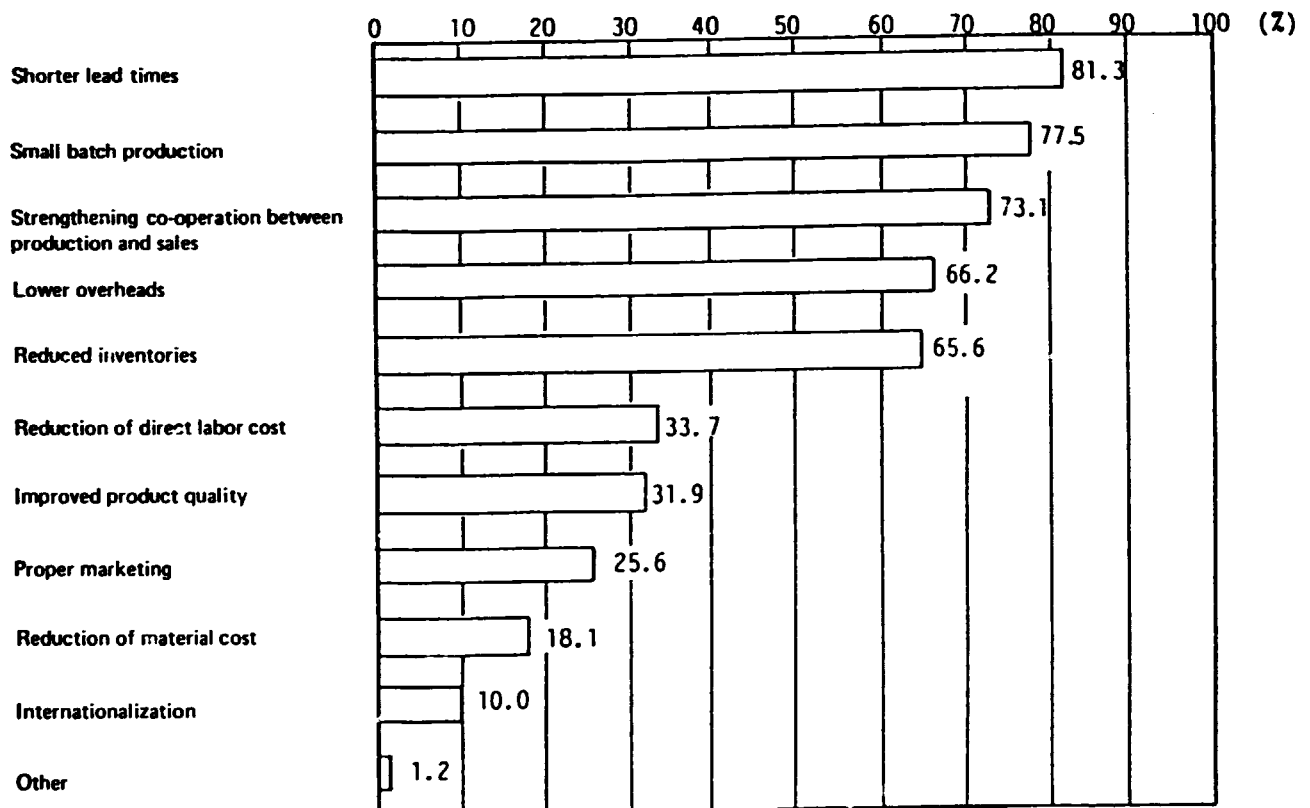


Figure 14. Changes in job content by CIM implementation
(Source: JMA 1988)

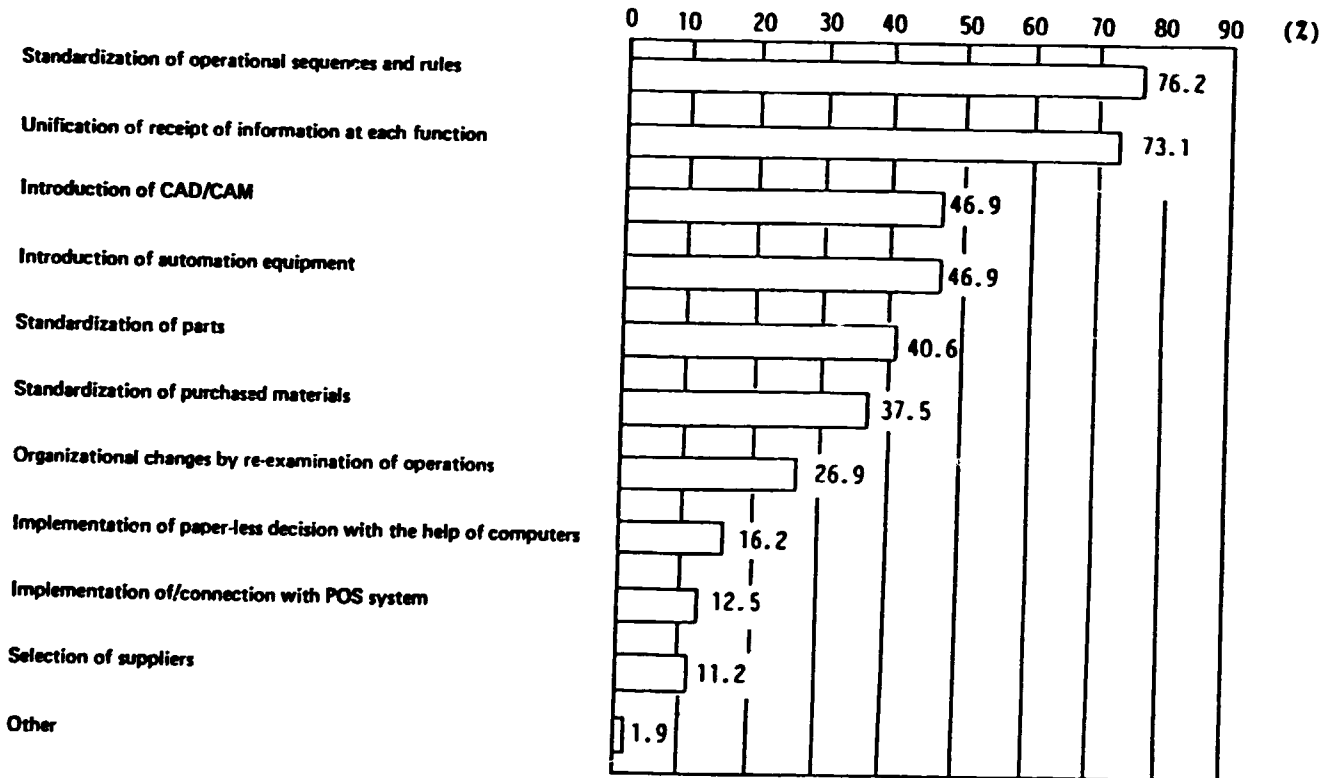
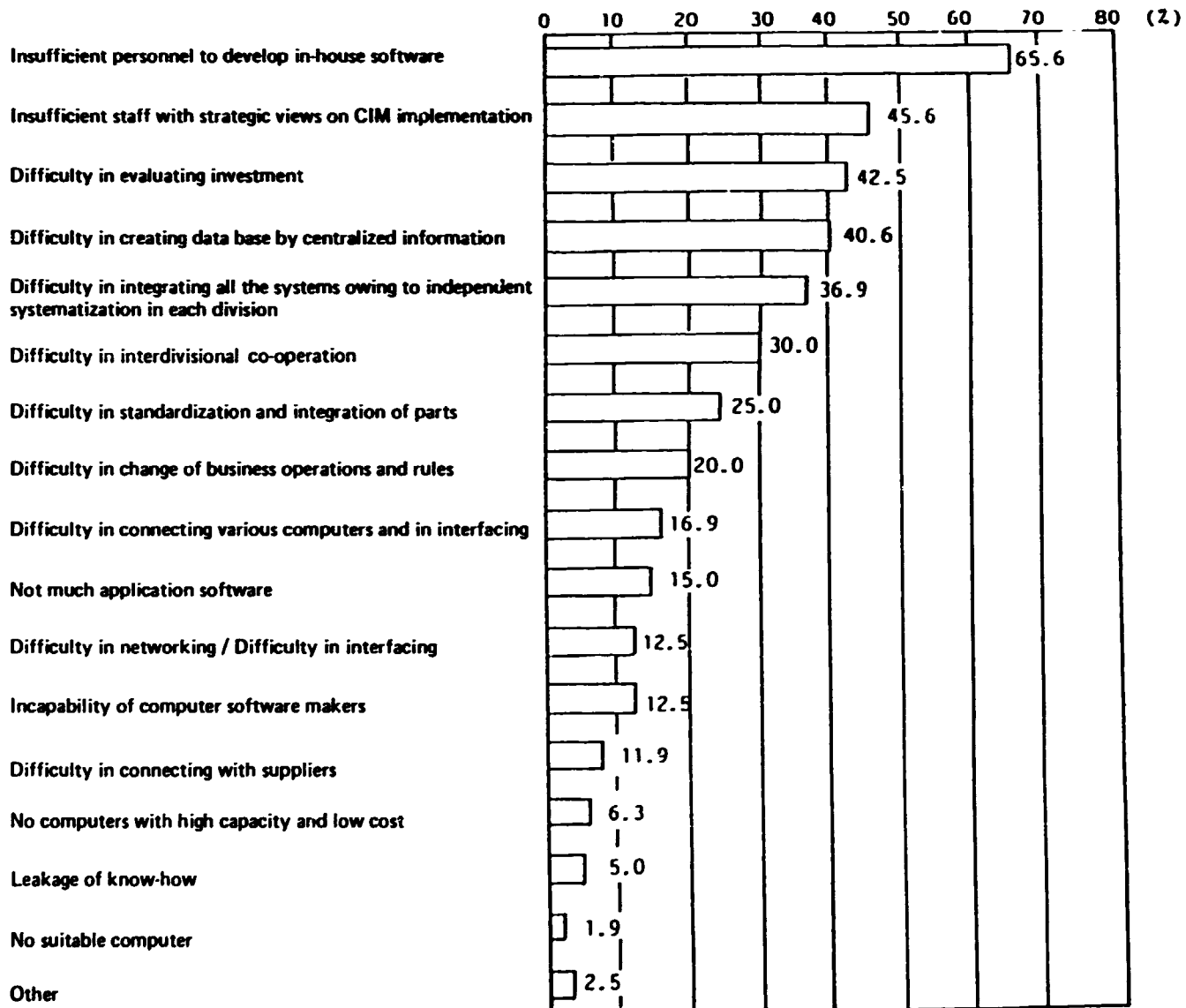


Figure 15. Problems encountered in the process of implementing CIM

(Source: JMA 1988)



5. CIM IN LARGE-VOLUME PRODUCTION

In Japan, comparatively more applications of CIM can be found in large-volume production. This is because CIM becomes more effective when it has been applied to large-volume production. This section discusses activities moving toward CIM in large-volume production.

5.1 *The history of automation in Japan and CIM*

The fundamental purposes of production management in Japan can be summarized in the following five points:

1. To minimize manufacturing cost
2. To manufacture only quality OK products by establishing a firm quality assurance system
3. To make lead-times as short as possible by minimizing inventory
4. To meet delivery dates
5. To make the workshop happy and bright in such a way that it is satisfying for the operators to work in it.

Basically, automation will be pursued by satisfying some or all of these purposes.

From 1950 to the first half of 1970 when there was ample demand in the market, Japanese advanced manufacturing companies mainly sought scale merits in automation, by automating step by step from a simple process (this is sometimes called point automation), a production line (line automation) and a product line (plane automation). Automation aimed at reducing the manufacturing cost by scale merits and assuring stable quality. In other words, it aimed at reducing or eliminating direct manual work as much as possible by creating a flow of products. In the course of automation, consistency and integration were constantly pursued. Shops of different functions such as machining and assembly were connected by increasing the reliability of each shop by the following steps:

1. Shortening physical distances between different functions
2. Synchronization between different functions
3. Direct connection.

After the first oil crisis, companies started to look for flexibility to cope with the new situations. They are now trying to obtain flexibility by synchronizing the material flow and the information flow. This automation (called solid automation) has basically the following two purposes:

1. Reduction of total manufacturing cost
2. Minimization of lead-times from receiving orders through production and to delivery in order to achieve quick response to the market demand of the diversified market.

The lead-times can be shortened mainly by proper hardware arrangement such as product-oriented layout, one-piece flow production and short set-up times. It is said in Japan that, roughly speaking, 80 per cent of the total productivity at the shop-floor level can be achieved by providing good reliable hardware while the remaining 20 per cent can be achieved by good software. FA covers the former 80 per cent and CIM is expected to take care of the rest. In the West, there are many reports of reducing manufacturing lead-times, say, from three months to one month, by implementing CIM. It may be worth mentioning that Japanese competitive manufacturing companies who can afford to implement CIM talk of lead-times in terms of higher hours or days, but not weeks. They are now trying further to reduce lead-times by implementing CIM. FA is mainly featured by laying stress on the automation of the workshop, but CIM makes it possible to unite different functions such as order receipt, production, delivery, facility maintenance, quality and safety by creating a flow of information with the help of information technology. CIM will eventually involve suppliers' networks as well. This could lead to further advanced CIM.

Figure 16 shows the ranking of various advanced manufacturing systems developed so far in terms of automation level.

Figure 16. Various advanced manufacturing systems

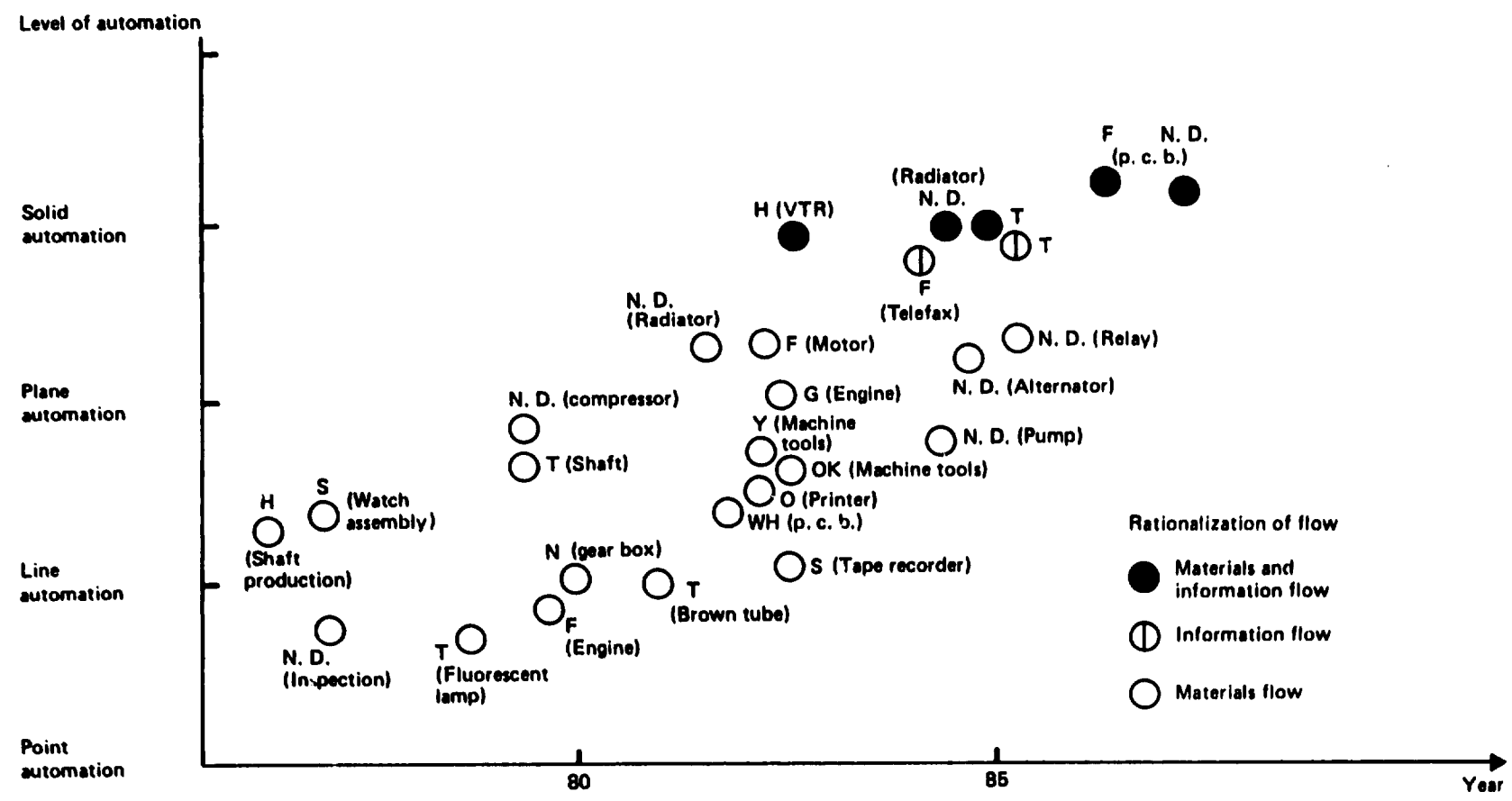
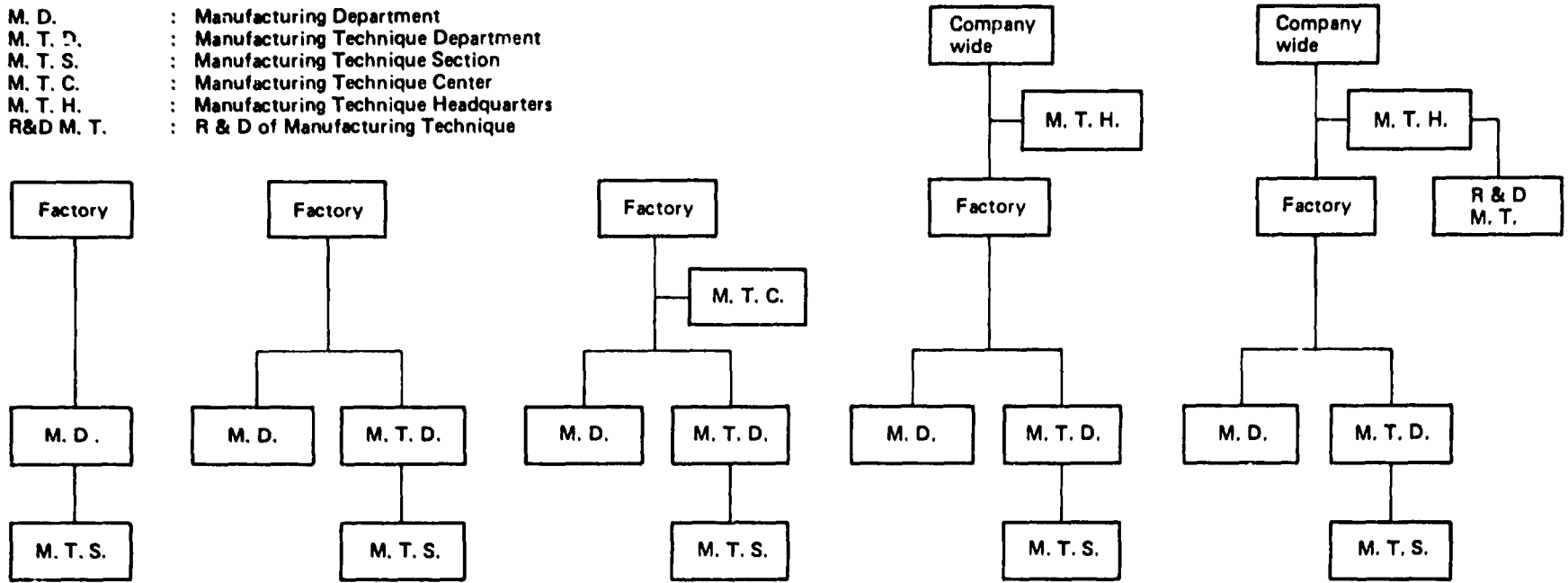
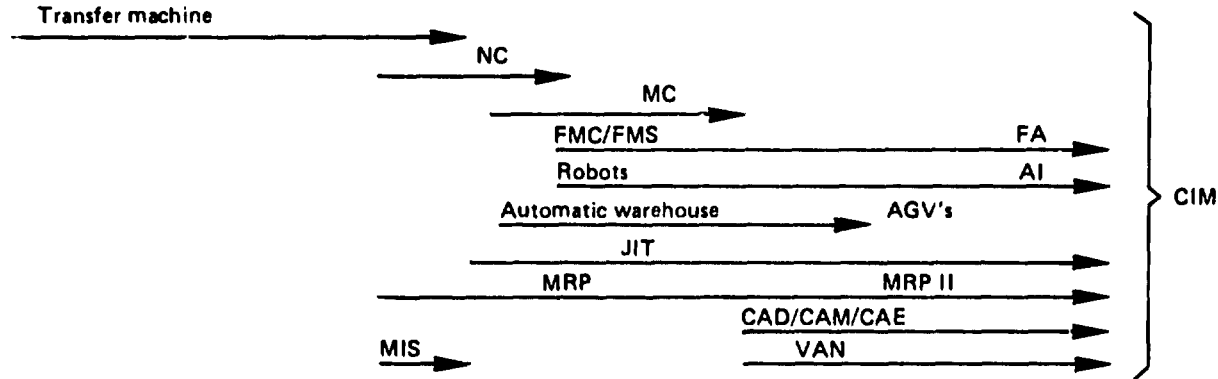


Figure 17. General trend of organizational change

- M. D. : Manufacturing Department
- M. T. D. : Manufacturing Technique Department
- M. T. S. : Manufacturing Technique Section
- M. T. C. : Manufacturing Technique Center
- M. T. H. : Manufacturing Technique Headquarters
- R&D M. T. : R & D of Manufacturing Technique



	V60	V70	V80	V85	Year
Point automation	Line automation	Plane automation	Solid automation	Level of automation	



Incidentally, figure 17 shows the general trend of organizational change together with the various manufacturing tools introduced to rationalize manufacturing after the Second World War. From this figure it can be seen that Japan is focusing more and more on the importance of production technology in order to have efficient and flexible manufacturing on the shop floor. As is easily understood from the figure, the strength of Japanese CIM lies in reliable manufacturing.

5.2 Quality assurance for CIM

In order for CIM to function properly, it is important for the manufacturing system to turn out products of stable quality. If the quality level is in terms of percentage, establishing a highly efficient CIM would be difficult since such CIM would involve much waste in order to take care of quality problems. Therefore, the quality assurance system plays a key role in establishing and operating CIM. Table 3 illustrates necessary activities for quality assurance from the design stage through daily production and up to the after-service stage in the market. Companies having excellent manufacturing techniques in Japan have already adopted such a quality assurance system and accumulated much know-how for establishing new manufacturing systems for new products.

The problem that has been left to further development of CIM is how to introduce new products into the existing manufacturing system without causing big problems. This is because it has become difficult to depreciate the system within the life-cycle of the product owing to the shorter product life-cycle. Thus, the establishment of CIM that can be used for products of several generations and how to put new products into such CIM have become a crucial concern in Japan.

5.3 Good maintenance for CIM

The success of automation also depends heavily on maintenance. If the level of maintenance is very low and if equipment cannot sufficiently be maintained because of bad maintenance, establishing a highly efficient CIM would be excruciating since such CIM would involve too much waste to take possible machine breakdowns into consideration.

The currently used time-based maintenance is becoming too costly as the degree of automation

advances. A more efficient condition-based maintenance has come to be demanded. When a breakdown takes place, it is quite important to detect the machine which caused the breakdown, repair it and recover the system promptly. However, the detection of breakdowns of facilities still must rely mainly on personal experience at the moment.

5.4 CIM to cope with diversification

Diversified demand will eventually lead to "production to order of mass-produced items with many variations." Although flexibility is required to meet diversified demand, it is not realistic to produce, say, from refrigerators to color TV sets by the same system. In other words, flexibility is required in the framework of a specific product, say, VTR to the extent that as far as VTRs are concerned, they should be produced by the same system. This system takes advantage of flow production of high efficiency, makes each process flexible, and produces only required products based on orders. In the production to order of mass-produced items with many variations, an operation at a machine or of an operator differs depending on each workpiece. Thus, it is vital to establish a proper operational control system to deliver information on when and what operation must be done to every part of the system. In the case of this control system, the "time" element plays a more critical role than in the case of lot production. For producing various products, if disorder occurs between processing information and the actual product flow it will create a serious problem. In this sense, reliable operation at each process and the information network system are very important.

To justify such a system economically and to operate it efficiently, standardization of design is essential. This starts investigating the market trend and establishing the basic models which will lead the market for a long period of time. Appropriate analysis of users' demand and standardization based on the analysis are vital. What users are after are only design and functions of products. Design of the new product must be made based on clear recognition of those parts which can be standardized and also by taking into consideration additional functions which would be in demand in the future market.

The strategy of "standardized design" means that each finished product is different, but that it mainly consists of basic standard parts.

Table 3.

Necessary activities for quality assurance

(a) Quality control of design	
*Reliable quality function	... Quality function development system
*Reliable product design	.. Specifications of parameters, specifications of tolerances
*Reliable quality assurance	... Design review, FMEA, FTA control of important points
*Reliable quality confirmation	... Reliability testing
(b) Quality control of manufacture	
*Design of reliable manufacturing	... Specification of parameters, specification processes of tolerances, investigation of process capability
*Reliable quality assurance	... Process FMEA, quality assurance over the entire process, control of important points, reliability testing during production preparations
*Total inspection of the critical processes	... Automatic testing, fool proof processes
*Reliable workforce	... devices, screening system, debugging system QC circles, evaluation of skills
(c) Evaluation of quality control activities	
*Evaluation of product quality (Evaluation of the <i>result</i>)	QC diagnosis QA meeting
*Evaluation of the quality assurance organization (Evaluation of the quality assurance <i>process</i>)	Quality auditing system

Product development in such a case is not possible by the product development department alone, but requires, from the stage of design, close co-operation among different departments, such as the production technique, quality assurance and production control departments. With such close co-operation, it becomes possible to make drawings of product shapes that facilitate production and the achievement of high accuracy, to improve quality, to adopt new material for reducing weight, to reduce the number of processes and to develop new methods to reduce material weight, etc.

There seems to exist strong sectionalism between different departments in western companies because of individualism. People tend to see problems only from the viewpoint of their department where they want to be recognized as specialists. Because of this sectionalism, many good co-operation schemes must be abandoned. Newly appearing industrial products are getting more and more complicated and highly value added. To produce such products, it is vitally important to organize people effectively and make them co-operate with each other.

Computer-aided systems like CAD and DNC display their abilities mainly by standardization that can be put into the data base. This will make it possible to launch on the market new products matching the market needs just at the right moment.

5.5 Interfaces

To synchronize the material flow and the information flow requires the exchange of information among operators, machines, products workpieces and computers. Such exchange can be achieved by some kinds of input-output devices as shown in figure 18. It is not too much to say that the success of CIM in large volume production depends on interfaces among various elements of the CIM. Good interfaces require reliability and minimum material handling if labour needs to be involved. This reliability means that no mistakes take place and that even if they take place prompt countermeasures can be taken.

Currently available input output devices are listed in table 4.

Although the bar code, OCR and magnetic cards are being used more and more as input devices in Japan, more sophisticated techniques such as the voice recognition techniques and the image-processing techniques are expected to be used in the near future.

6. EXAMPLES OF CIM IN JAPAN

This section introduces three good examples of CIM which proved to be very useful in Japan.

6.1 CIM for Minimal Inventories

6.1.1. Pull system (Kanban) and push system (MRP) for JIT manufacturing

Table 5 gives definitions of Kanban and MRP systems and figure 19 shows a comparison between Kanban and MRP systems concerning order fixed timing.

Because of the difference of order fixed timing between Kanban and MRP systems, each system has a drawback as shown in figure 20.

1. Pull system (Kanban)

With this pull system, there are buffers before and after each manufacturing line. Thus, if a manufacturing line has to process many different parts, then the total stock level before and after the line becomes unacceptably high. For example, even if the line has to produce of a certain part only one unit per month, this unit must still be stocked in the form of an unprocessed unit before the line and a processed unit after the line. Thus, the pull system can mainly be used for repetitively used items.

2. Push system (MRP)

With this push system, if the production schedule changes, then the items which have already been partly processed and which turned out to be unnecessary must be stocked. Actually, many companies in Japan after using an MRP system, have experienced the following problems:

- Dead stock and work-in-process will increase because of schedule changes needed to meet market demand.
- There are more missing parts at assembly because of schedule changes.

Figure 18 Exchange of information via interfaces

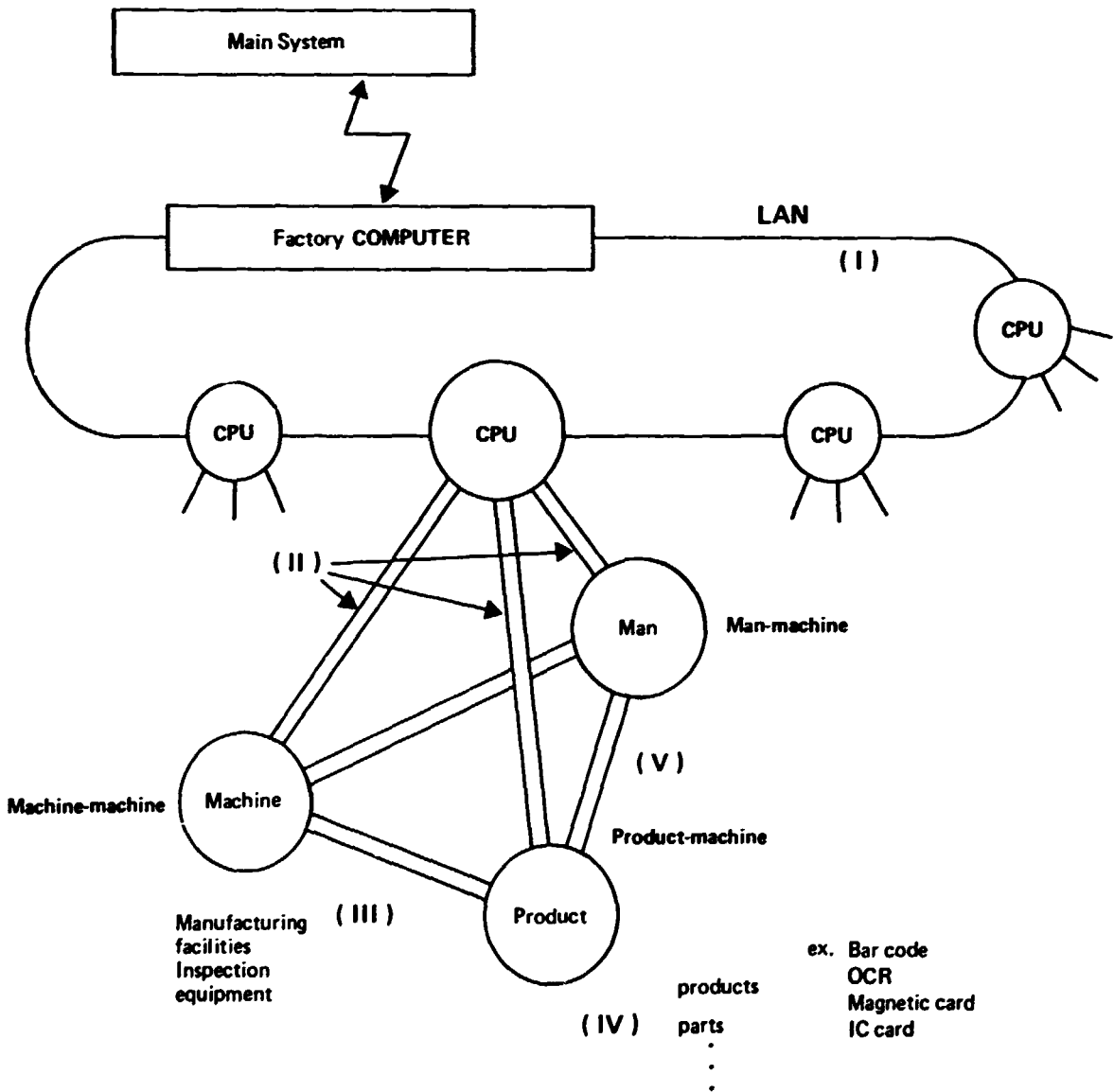


Table 4. Input - Output Device

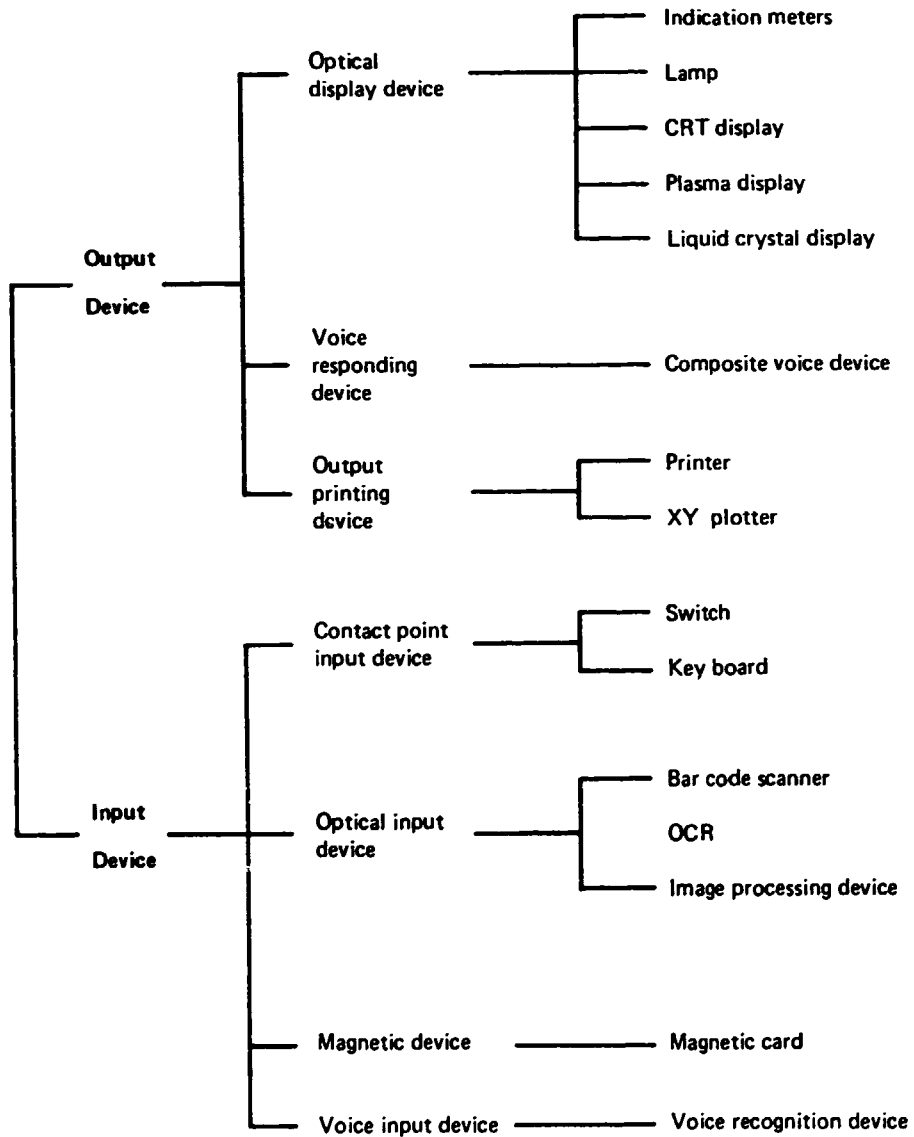


Table 5.
Kanban and MRP systems

Item	Kanban	MRP
Definition (content)	A kind of tool to manufacture or buy as many parts as have been withdrawn (sold) just in time	Weekly order method of unfixed quantity
1. Difference in philosophy	Dominated by the levelled production schedule based on market needs with adjustment possibility (Market - in)	Dominated by the production schedule (Product - in)
2. Difference in method	Pull system from assembly (the process close to the market)	Push system to the 1st process (in the workshop)
3. Control time unit	Daily production and ordering method based on the weekly assembly schedule	Weekly (or every ten days) ordering method based on the master schedule

Figure 19. Order fixed timing

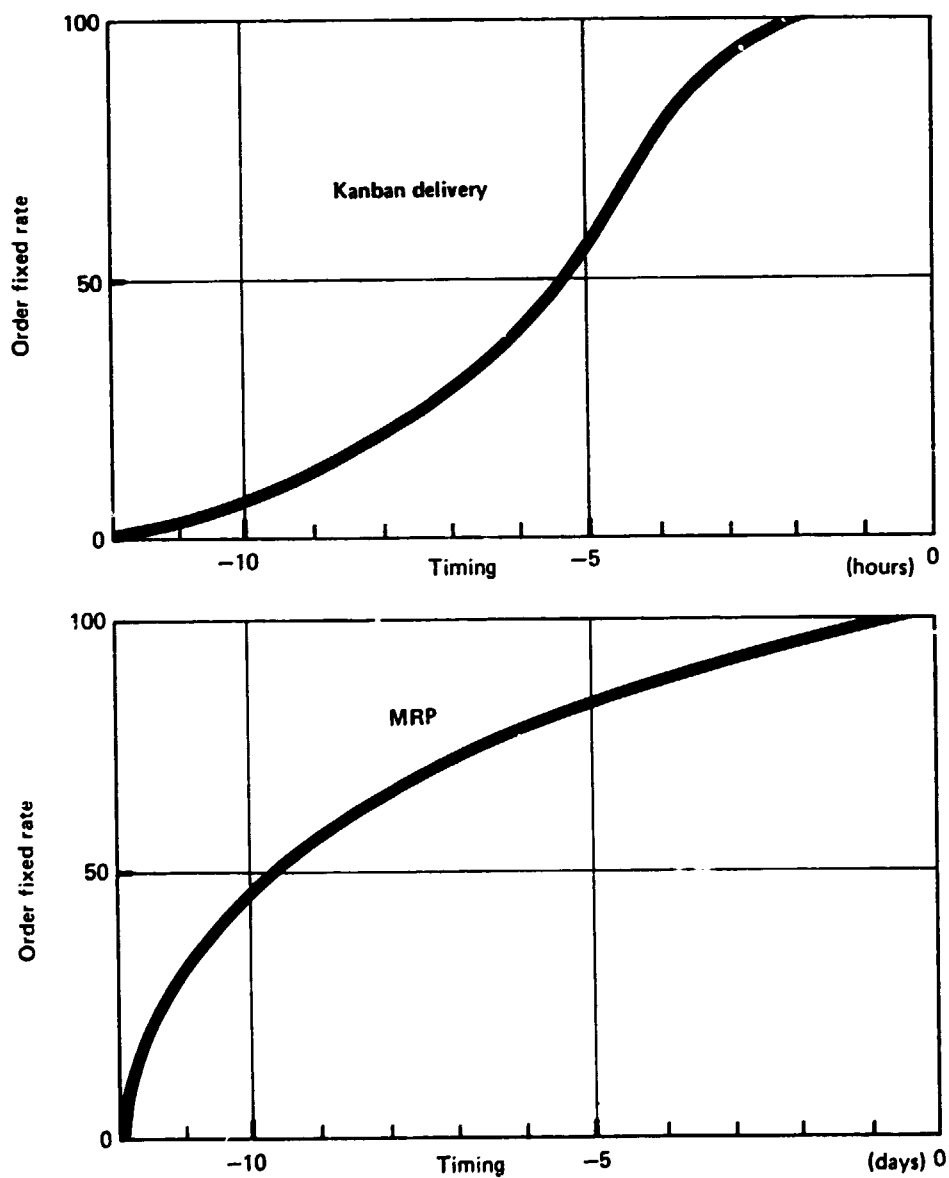


Figure 20. Drawbacks of Kanban and MRP systems

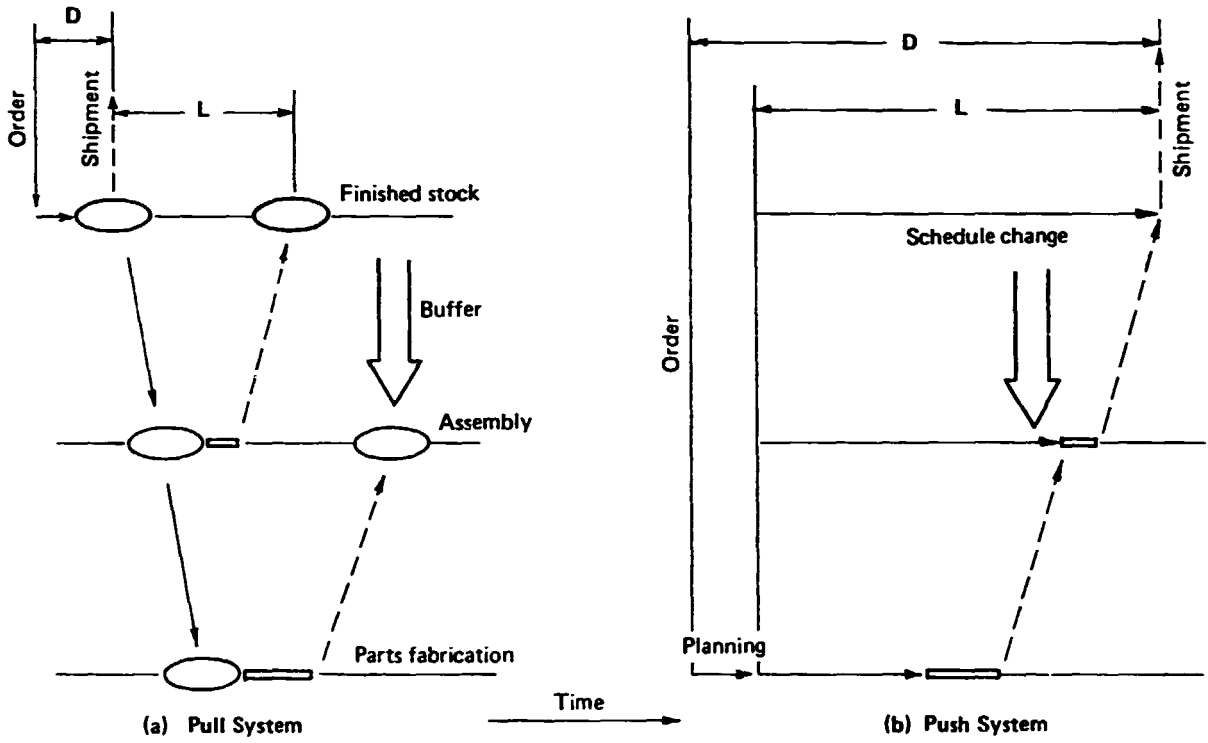
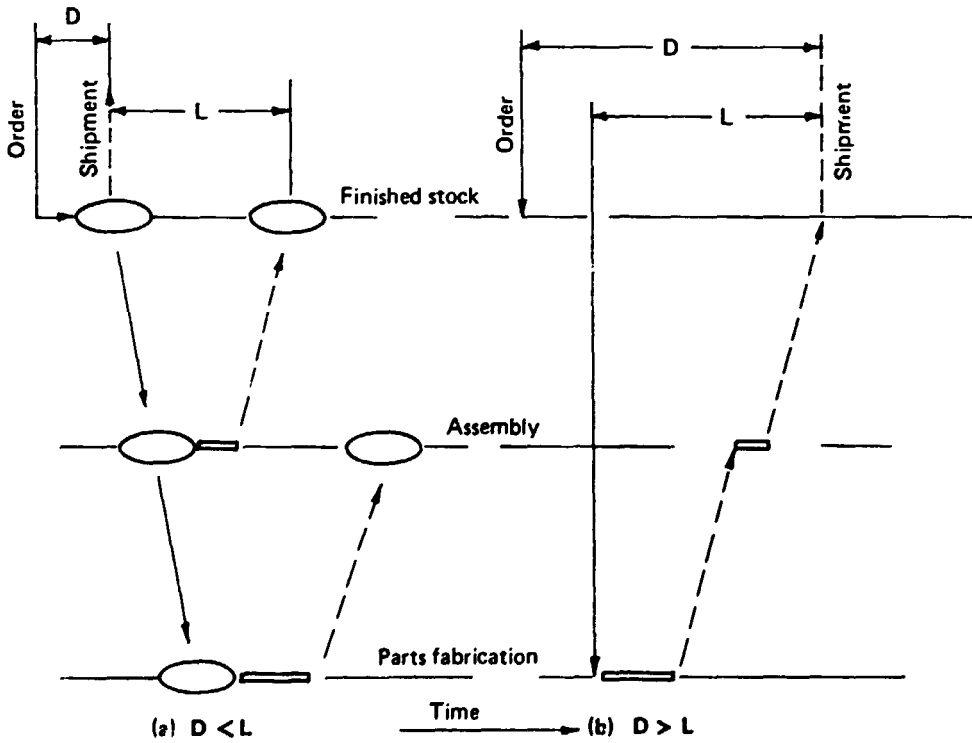


Figure 21. Combination of pull and push systems



6.1.2 Possible combinations of Kanban and MRP systems for minimal inventories

1. Case 1 : When the production schedule is made based on real orders.
2. Case 2 : When the production schedule is made based on a concrete sales plan.

In these two cases, MRP could be used for purchasing necessary raw materials and components which can be stocked in the warehouse. Kanban can be used for manufacturing orders and delivery information within the plant.

3. Case 3 : When production lead time is short enough and when the production schedule is made based on the minimal delivery unit.

In this case, it becomes possible to combine pull and push systems to minimize buffer stock and to accommodate for sudden changes as shown in figure 21.

An auto component supplier in Japan has already implemented this combined pull and push system for producing radiators and succeeded in meeting the demand on time and at the same time minimizing the finished stock for the customers. This type of CIM in the factory needs a reliable network to connect different branches and careful consideration for the interfaces among man, machine, product and computer, as discussed in the previous section. To develop such CIM requires good human resources to establish the data base and to make the system software. The company says that the keys to the success of the system are the maintenance and the incremental improvements of the system.

6.2 CIM for customer-oriented production

Customer-oriented production means production not based on dealers' demands but based on real customers' orders with short delivery time.

Let us look at an example from the automobile industry. Figure 22 shows the possible combinations of body types, body colours, engine types, seats, transmission and so forth. For one basic model of the car, there are normally several thousand possible combinations. Thus, to forecast each real customer's needs precisely is impossible. Some Japanese car makers already carry out customer-oriented production: the production schedule is made based on the sales forecast but the real production is made based on customers' orders. They make monthly production schedule concerning production volume

and basic models to be produced based on the sales forecast. This is made three months ahead. Then the schedule is adjusted every month. They divide each month into three ten-day production periods. Ten days before each ten-day production period, they make the master production schedule for the period and in a way freeze the schedule, but still accept changes of specifications if the changes are made four days before the production day, as shown in figure 23.

Figure 24 gives three conditions for customer-oriented production, i.e., manufacturing based on customers' orders, shortening of production lead-time and timely procurement of purchased goods. CIM involving order entry system, synchronization and multi-delivery system is the solution to materialize this customer-oriented manufacturing system as shown in figure 25. The configuration of this CIM takes a hierarchical, decentralized, autonomous and co-operative form with the standardization of interfaces among system components. Some Japanese car makers use this CIM to achieve production efficiency.

6.3 CIM to integrate production, sales and distribution system

6.3.1 Investigating market demand

Generally, based on the forecast of demand, a sales plan is established. The sales plan is the starting point for making all the other plans such as production plan, distribution plan, inventory plan, material procurement plan, etc. There will be a mountain of goods if demands are lower than estimated and there will be a shortage of goods if demands are higher than estimated. Thus, it is very important to establish a good and firm sales plan. In other words,

1. The accuracy of the forecast of demand is very important.
2. The gap between the sales plan and the actual sales results must be checked as early as possible (preferably daily, if this is not possible, then weekly).

Since companies cannot control the market, estimation errors are liable to take place. Distribution information can play an adjustment role between production and sales. Its major roles are to ascertain the sales situations of the company's products in the market as early as possible, to clarify the gap between the sales plan and the actual sales results and to feed back the information to the production and sales divisions.

Figure 22. Possible combinations for producing cars

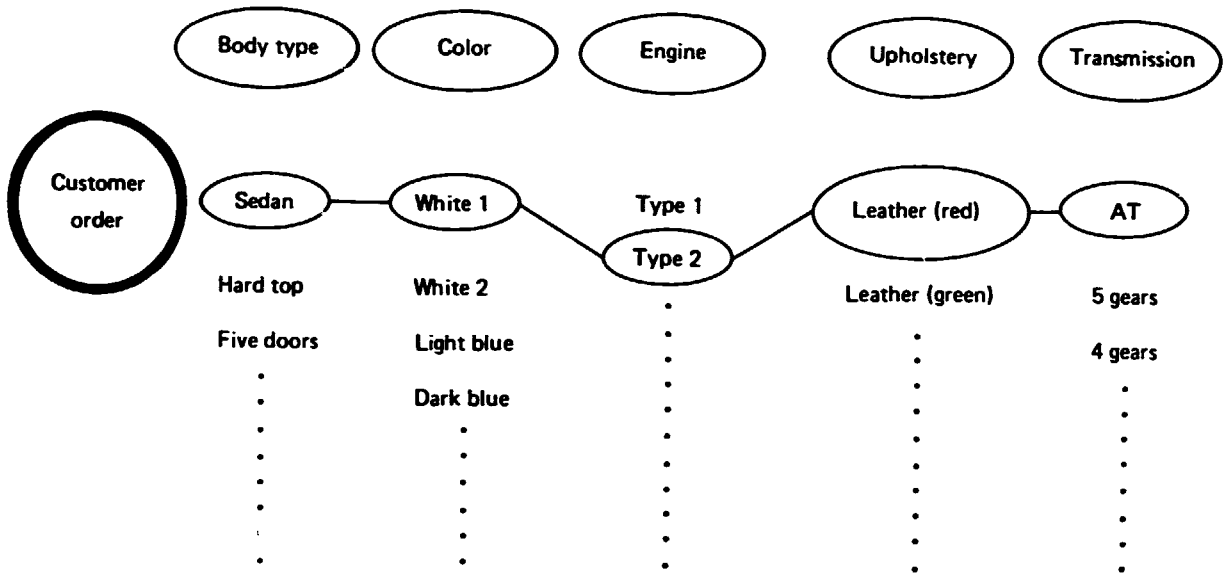


Figure 23. Production schedule for customer-oriented production

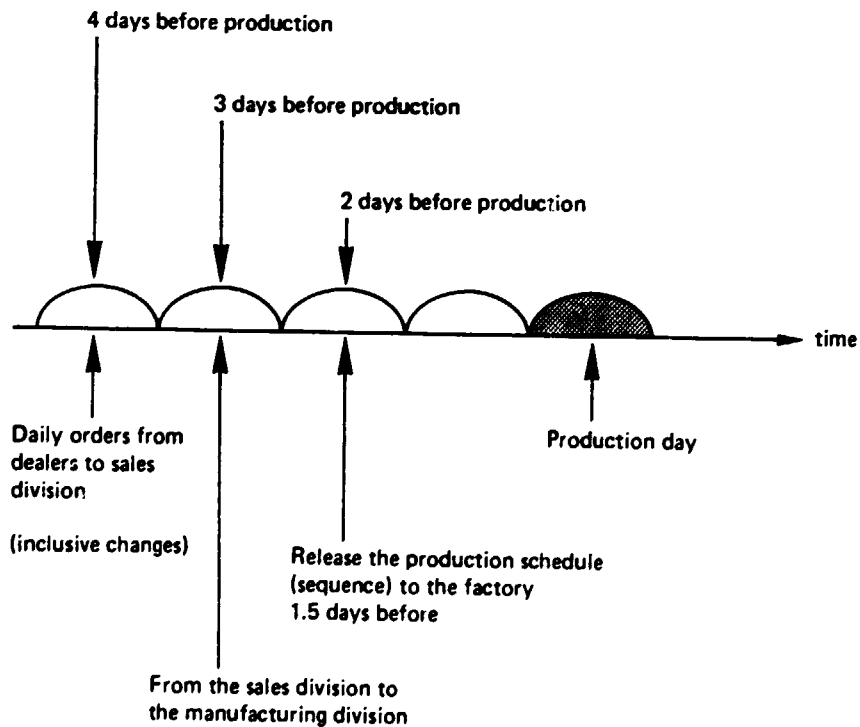


Figure 24. Three conditions for customer-oriented production system

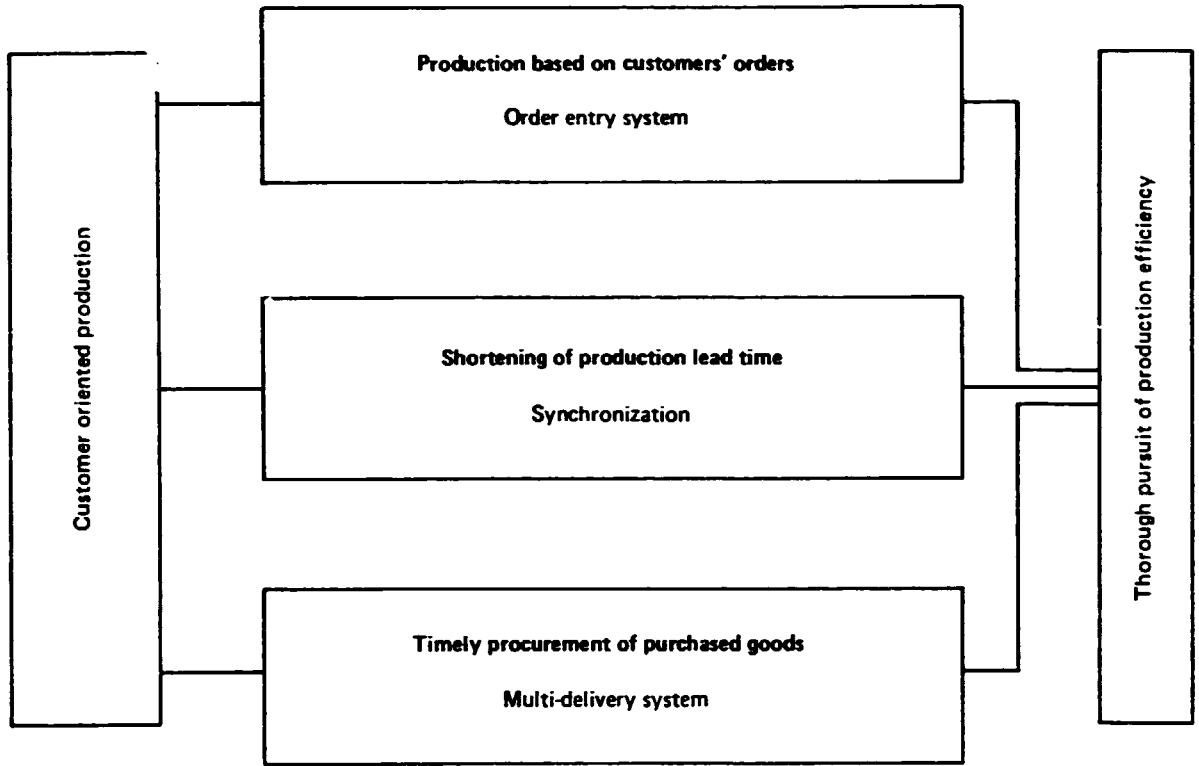
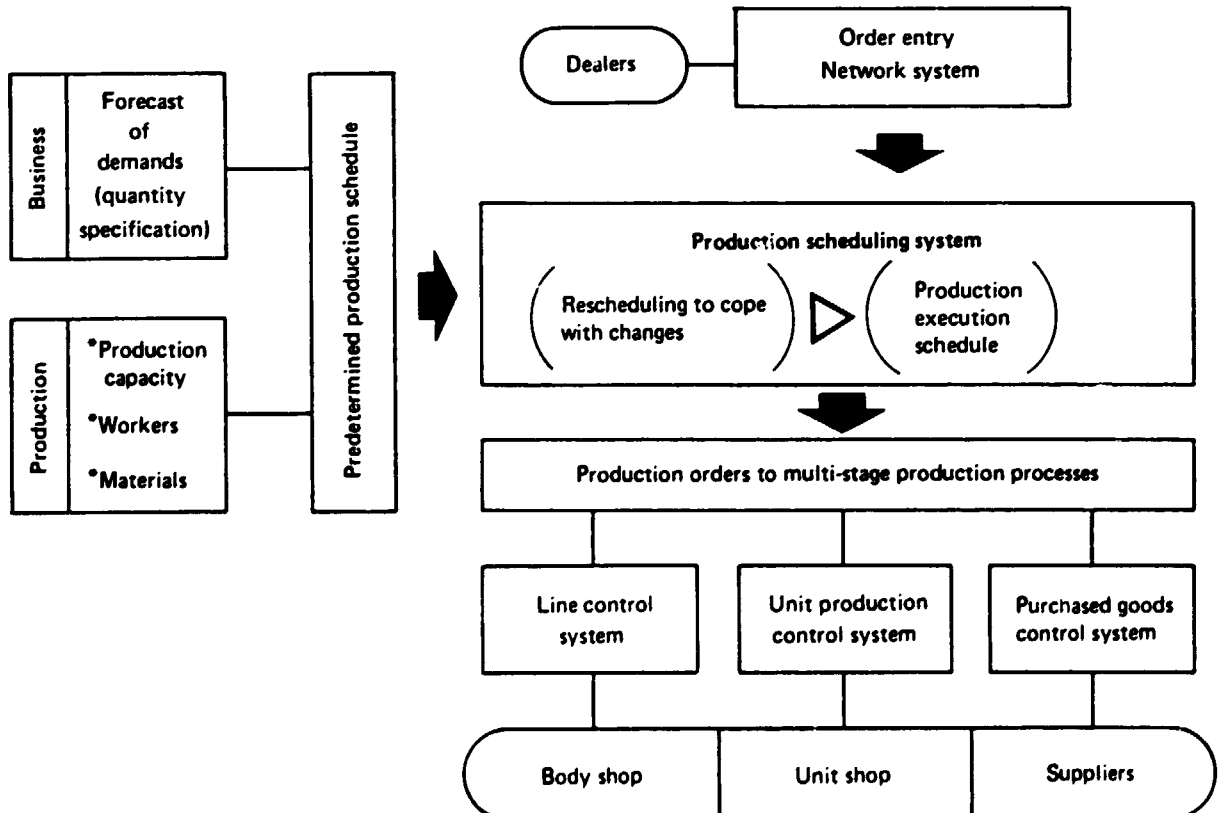


Figure 25. Production expansion



6.3.2 *Two requirements for the distribution system to investigate market needs as early as possible*

In order for the distribution system to play this role, it is required to satisfy the following two requirements:

1. To have an organization which grasps the delivery information, the inventory information and the shortage information in order to see the market movement.
2. To grasp such pieces of information on each product.

Based on those pieces of information,

1. Production of the articles in poor demand must be stopped and new articles must be developed.
2. Production of the articles which sell better than estimated must be increased. The cause of the high sales must be pursued and new products based on this investigation of the causes must be developed and launched on the market as early as possible.
3. If some article sells well in certain areas and not in others the reason must be pursued. It may be that the sales activity in the poor demand areas must be strengthened, or it may be necessary to limit the sales areas of the article.

6.3.3 *Integrated production, sales and distribution systems*

When the distribution system can play such a role, it becomes possible to integrate production, sales and distribution into a system. In order for the system to function properly, it is vital:

1. To be able to grasp the delivery information, the inventory information and the shortage information daily or weekly.
2. To have a firm sales and production plan as the base.

3. To have a system in which it is possible to take proper measures immediately.

If any of these are missing, the integrated system will not function.

6.3.4 *Case study*

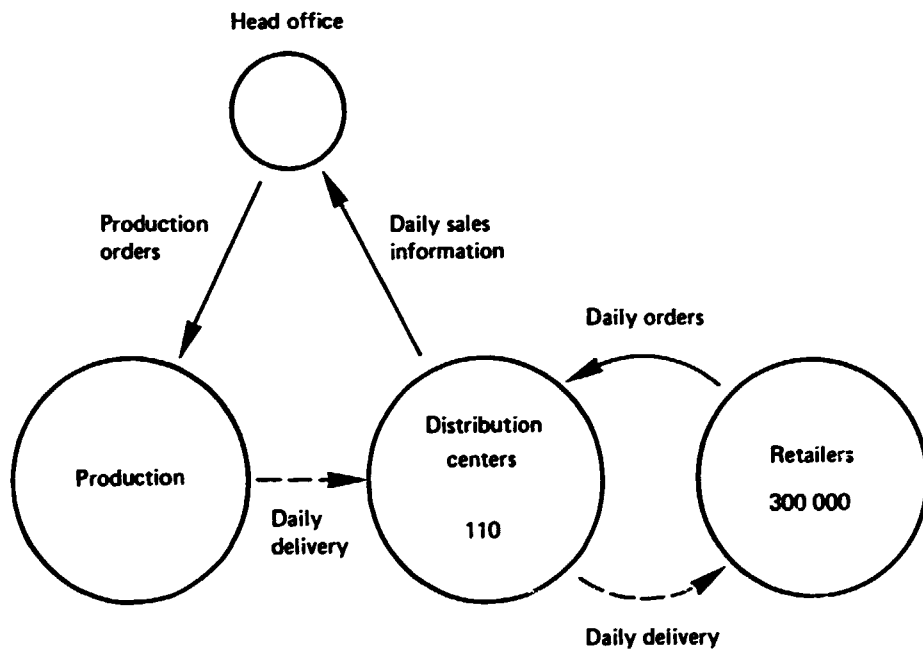
In Japan, the iron and steel industry and the textile industry is advanced in CIM to integrate production, sales and distribution.

As an example of an integrated production, sales and distribution system, let us examine one of the biggest sanitary goods makers in Japan.

This company has a head office in Tokyo, eight operation centres and about 110 distribution centers in various places in Japan as shown in figure 26. There are about 300,000 retailers which sell their products all over Japan. Between the retailers and the distribution centers, there are daily orders and daily deliveries. The company says that with this system a customer can get any product within 24 hours.

The delivery quantity and receiving quantity of each article are input daily to the computer terminal of each distribution center. The host computer at the head office collects on the same day the data on these pieces of information and checks for major items the difference between the planned sales quantity and the actual sales quantity regarding every article at every distribution centre. If the difference for any article exceeds more than 30 per cent, the computer gives a warning. Concerning this article, a meeting among the concerned production, sales and distribution people takes place. When they see the possibility that the gap will increase, they change the predetermined production plan and also the material procurement plan. The distribution plan will also be adjusted. As for those items whose gaps stay within their limits, production and delivery are made based on the predetermined schedules.

Figure 26. Integrated production, sales and distribution system



The delivery quantity and receiving quantity of each article are input to the computer terminal of each distribution center.

The host computer calculates for other articles the stock levels of those items and compares them with the predetermined stock levels. If the stock level of a certain item becomes lower than the predetermined stock level, then its stock will be replenished with a certain fixed quantity.

In this way, the plan and actual result are compared daily for every article at every distribution centre.

Based on this investigation, the host computer gives orders daily to production in the following way:

... X pallets of detergent to A distribution centre
... Y pallets of shampoo to B distribution centre

The company, by having this kind of integrated production, sales and distribution system, has succeeded in meeting the market demand on time while minimizing the finished stock between production and sales. Unless production, sales and distribution are integrated properly, delivery of any goods within 24 hours would be extremely difficult. The company increased its sales by 1.4 times over the past 5 years and its profit by 1.7 times. This is said to be one of the most successful implementations of CIM in Japan.

SUMMARY

The major findings of CIM in Japan can be summarized as follows:

- (1) In order to cope with the current mature economic climate, Japanese advanced manufacturing companies expect CIM to play a key role in the processes from market investigation to customer delivery.
- (2) There are differences between Japan and the West regarding CIM concepts and approaches. One feature of Japanese CIM is that CIM tends to be understood in a broader sense to mean *Computer Integrated Management*.
- (3) Many Japanese manufacturing companies consider it useful to implement CIM in the areas of manufacturing, order receipt, production design and production preparations, material procurement, sales and distribution.
- (4) CIM is assumed, from the lesson of the failure of MIS, to take a hierarchical, decentralized, autonomous and co-operative form with the standardization of interfaces among system components.
- (5) The prerequisites for implementing an efficient CIM are good quality assurance and maintenance, together with suitable interfaces among computers, machines, products/workpieces and operators.

Notes

- (1) *H. J. Ansoff: "A Model for Diversification", Management Science, Vol. 4, No. 4, p.99.*
- (2.1) *Hackstein, R.: "CIM-Begriffe sind Verwirrende Schlagwörter - Die AWF - Empfehlung schafft Ordnung!" Tagungsband des AWF-Kongresses PPS 85, Boblingen 1985.*
- (2.2) *CAM-I: "An Architecture of CIM", R-88-ATPC-01, 1988.*
- (2.2) *CIM-Wheel* by SME.

MANUFACTURING ORGANIZATION FOR COMPUTER-INTEGRATED TECHNOLOGIES

by P. SIMMONDS, Brighton Polytechnic, Brighton, United Kingdom

Introduction

Companies in the United Kingdom like those in most other European countries, have placed much emphasis on the introduction of advanced manufacturing technologies in order to enhance competitiveness and ultimately stimulate the regeneration of beleaguered manufacturing sectors.¹ But, despite the availability of sophisticated systems and an apparent willingness to invest, the majority of British engineering firms have found implementation problematic and the promised benefits slow to materialise.

This is a message borne out by Europe-wide research and perhaps more interestingly in the latest reports of several international management consultants. Organizations such as Booz Allen & Hamilton and AT Kearney, who talked only of system integration five years ago, are now advising companies that their investments in CIM need to be complemented by extensive socio-structural investments.

This does not negate the need for change or for technological development. It does, however, suggest that the trend towards computer-integrated manufacturing systems is incremental rather than revolutionary and very much dependent on people.

The economic rationale behind the need to develop more human-centred systems was summed up in the statement by the President of the giant Matsushita Corporation, Konosuke Matsushita: "we are beyond the Taylor model... the survival of firms ... depends on the day-to-day mobilization of every ounce of intelligence. For us the core of management is precisely that art of pulling together the intellectual

resources of all... in the service of the firm... The intelligence of a handful of technocrats... is no longer enough (to take up the new technological and economic challenge) with any real chance of success."²

Human Factors and Integrated Manufacturing

It has become clear that simply investing in what we euphemistically call Computer-Integrated Manufacturing (CIM) technology is no guarantee that a company will be better able to cope in an increasingly global and highly differentiated marketplace. This is, in part, because the development and exploitation of technology is in itself a dynamic process fraught with risk for the innovator.

However, earlier work carried out at the Centre for Business Research, on Computer-Aided Engineering (CAE) and Flexible Manufacturing Systems (FMS), concluded that some of the most immediate reasons for the limited commercial success were structural rather than technical. Figure 1 details some of the barriers to implementation that we came across during the course of our research.

Conclusions from the FMS studies were that the majority of benefits accrued from what has been termed the "computerization effect". The process of self-reflection and the use of more human-centred methods, such as JIT, had brought the biggest benefits. Expectations that the "hard technology," with its inherent re-programmability would lead to greater product innovation and rapid customer response, had not materialized: companies, for the most part, did not even re-program systems.³

¹ Manufacturing Organization for Computer-Integrated Technologies (MOCIT) is a collaborative project between the Centre For Business Research (CBR) in Brighton and the Change Management Research Unit (CMRU) in Sheffield. The CBR is the business research arm of the Brighton Business School; and the CMRU carries out a similar function at Sheffield Polytechnic. The two year programme is being funded by a joint-committee of the British Science and Engineering Research Council (SERC) and the Economic and Social Research Council (ESRC).

² Personal communication quoted in John Bessant and Alec Chisholm's "Human Factors in Computer-Integrated Manufacturing" in Tom Forester's (ed) *Computers in the Human Context*, 1989.

³ See Bill Haywood and John Bessant's "FMS and the Small to Medium Sized Firm" and "The Swedish Approach to the Use of FMS," 1987. CBR Occasional Papers nos. 2 & 3 respectively.

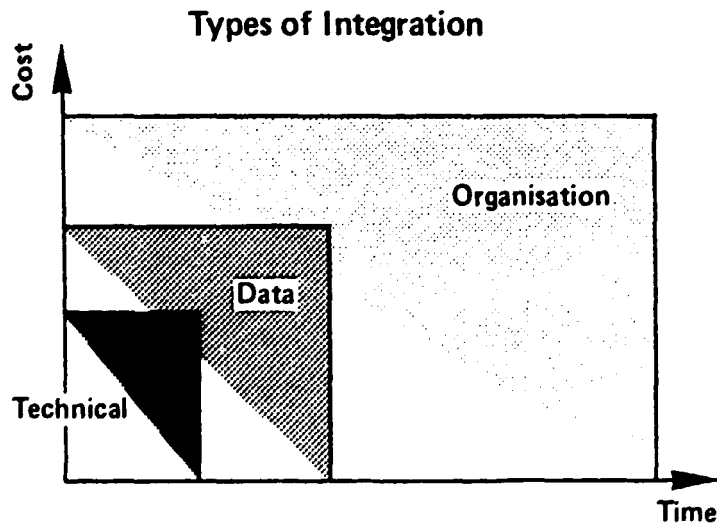
Figure 1.

Manufacturing Organisation for Computer-Integrated Technologies

Barrier	Causes
Structural	
Excessive focus on direct labour	Obsolete Decision Criteria
Failure to perceive True Benefit	Lack of measures of intangibles
Lack of Co-ordination and Cooperation	Organisational Fragmentation
Human	
Uncertainty Avoidance	Fear of Change
Resistance	Fear of loss of Power or status
Competence	Skill as COST
Technical	
Incompatibility of systems	Limited Connectivity of Available systems

Figure 2.

Manufacturing Organisation for Computer-Integrated Technologies



Our research also found that management had consistently underestimated the magnitude of the problems involved in the transition from an organization tuned to conventional mechanization to one using integrated, computer-based systems. The management consultants AT Kearney came to a roughly similar conclusion in their 1989 survey of 3000 United Kingdom manufacturing companies. Figure 2 is drawn from this study and illustrates the idea that the greater the technological change the greater the structural upheaval and the cost and time involved in making that change.

There is widespread need for organizational change. Our experience is that the majority of United Kingdom manufacturing companies are characterized by product-based management and functional fragmentation: the existence of separate departments for development, production, finance, marketing etc. mediated by people and materials appears inappropriate to the information-intensive nature of CIM. In simple terms, it would seem that computer-based, information-intensive technologies require more integrated and information-sharing organizational forms.

While there is now a considerable body of anecdotal and case-study evidence which suggests that some degree of organizational and administrative adaptation is necessary, the majority of practitioners still do not consider organizational or cultural factors as important design variables.

Organizational Structure, Technological Choice & Manufacturing Strategy

The relationship between technical systems, organizational structure and the environment has been extensively theorised over the years from the earliest work of people like Joan Woodward in the 1960s to the more recent work of John Child, in the United Kingdom or Henry Mintzberg in United States.⁴ In general the relationship is now seen in terms of choice conditioned by strategic contingencies: around product, process, market, and other environmental factors with the internal choices around organizational design and technological system (figure 3).

This has given rise to a theorised model or blueprint of organizational design for integrated manufacturing

which can be characterized along a number of dimensions. What some have termed the "post-fordits" or "flexible" organization is likely to be based on cellular manufacture and group technology with autonomous, multi-skilled work groups: greater co-operation between functions and much tighter vertical organization (between suppliers and customers) etc.

The immediate problem with such a model is the tendency to generalize. There are many variants of manufacturing systems designed to suit an equally wide variety of products and circumstances. In practice, the scope of choices available appears to permit many different organizational configurations, all with the objective of improving manufacturing performance. There is, therefore, a need for tighter definitions and greater clarity about the relevance of individual organizational developments to manufacturing strategy and ultimately to business strategy.

MOCIT

There is, as yet, little detailed work on the exact dimensions of these organizational developments. Hence the MOCIT programme which is attempting to map the organizational and cultural dimensions of a number of "best practice" integrated manufacturing companies, each with some degree of congruence or fit between their strategic orientation, structural position and technological system. Figure 4 lists some of the primary organizational design variables which are expanded upon below.

Functional Integration

One of the most important organizational issues concerns the effect on existing functional boundaries. CAE and FMS, by definition, integrate, through networked computer systems and databases, the formerly discrete activities of manufacturing - design, process planning, co-ordination and production. CAE and FMS also imply new and closer relationships with marketing. If the systems allow reduced lead times and flexibility (however constituted), it should through improved communications with marketing, enable the organization to be more responsive and proactive.

⁴ Joan Woodward, "Industrial Organization, Theory and Practice," Oxford University Press, 1965. John Child, "Organizational Design for Advanced Manufacturing Technology," in Wall *et al* (eds), 1987. Henry Mintzberg, "The Structuring of Organizations" (1979) and "Structure in Fives," 1988.

Figure 3

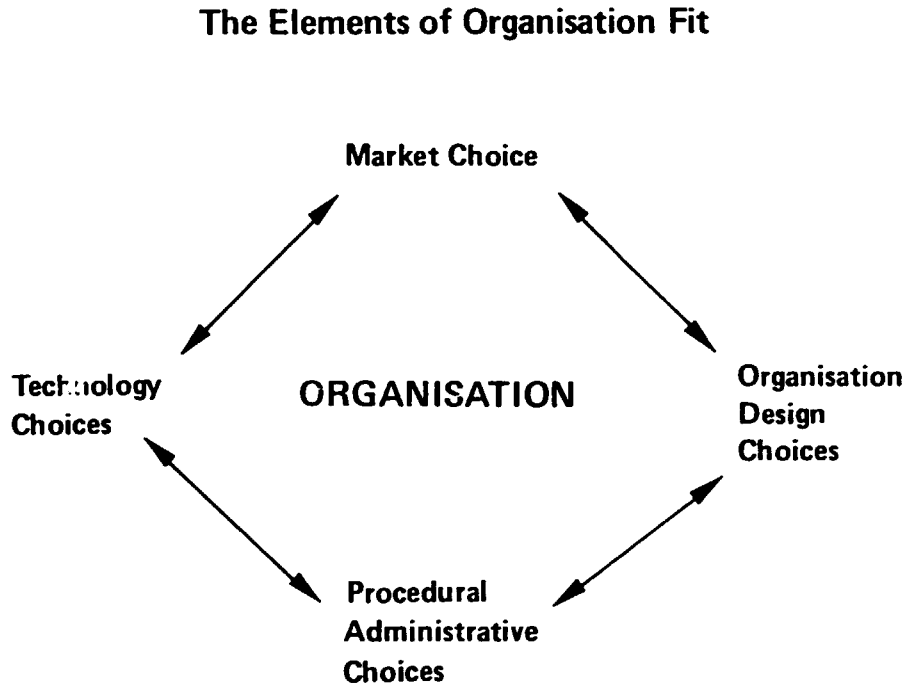
Manufacturing Organisation for Computer-Integrated Technologies

Figure 4

Manufacturing Organisation for Computer-Integrated Technologies**Dimensions of change****Skills****Functional Integration****Work Organisation****Organisational Hierarchy****Culture**

However, this is not simply about production, engineering and marketing talking to each other, although in the majority of British manufacturing firms this would be a significant improvement: it should go further to impact on the content of the work. In order for the organization to benefit from the greater innovative potential of the CAE system, for example, or the adaptability and rapid response of the FMS system, there would have to be a commensurate improvement in the effectiveness of marketing research.

The challenge to existing boundaries does not stop within the organization and should ideally be extended to both suppliers and customers through much closer and more interactive relationships. The coming together of an engine design company with its automotive customer and machine tool supplier, around a common CAE strategy has led to individual engineering workloads being conducted in parallel rather than in sequence; and with greater cross-fertilisation of ideas. The result has been an immediate reduction in project development times, by around 25 per cent and substantial savings in rework and engineering changes.

Impact on Manufacturing Methods

One area which is consistently mentioned by organizations is the inappropriateness of existing accounting methods to the evaluation, justification and development of such capital-intensive and integrative technologies. The costs and benefits of these systems are not borne solely by the implementing group or department. A hand power tool manufacturer that revised its marketing and market research effort to complement an FMS investment is a case in point. Traditional accounting measures of effectiveness became redundant.

This resulted in production making a conscious shift from measuring in terms of direct labour hours to final product cost (this included scrap, rework, support activities etc). This costing or methods of evaluation was still too localised and did not include the knock on effects of the marketing re-appraisal. A manufacturer of printing machinery ran an FMS set up in parallel with its conventional systems and found itself running two accounting procedures.

Work Organization

At the level below function, these systems have had an effect on work organisation. FMS for example has displaced many of the conventional craft roles, the knowledge of machining and materials is partly embodied within the system but has also moved upstream into the engineering and co-ordinating roles and perhaps most importantly into those responsible for programming. On the shop floor, the human element has really shifted from that of doer to that of monitor and manager.

With respect to work organisation the main choice concerns the degree of homogeneity in the job structure. At one extreme a number of British companies have maintained pre-existing and highly differentiated job structures after investing in FMS. In this case there was a polarisation of skills, with the programming and support functions being carried out by service units from other departments, while production people were relegated to materials handlers. At the other extreme, two Swedish companies were using highly skilled work teams of graduate engineers. The latter is perhaps the ideal as it arguably provides a social-correlation to the integrated and multi-functional nature of FMS.

The majority of companies visited fell between these two options. For example, an outside service group may be used for primary programming activity, while internal groups take responsibility for control monitoring, program modification and most maintenance tasks. Management is faced with a difficult decision between the easier method of relying on third parties and internal service groups to achieve faster if partial benefits; and the effort, cost and risk of trying to develop the more appropriate skills and work structures from the outset.

Integrated Manufacturing and Culture

Of course, the majority of people would support the autonomous, multi-skilled work team approach for CAE or FMS, but there are a number of limiting factors. A commercial vehicle engine manufacturer mentioned the practical difficulty of introducing a labour-enhancing, non-hierarchical experiment into a highly differentiated and hierarchical organisation. Single status, multi-skilled work teams were a cultural shock and threatened both managers and operators alike, with the result that the company fell back on the polarised work organisation mentioned earlier.

The question for management was how to negotiate such a fundamental shift in cultural values and

expectations: quality, single status, collectivised responsibility, continuous improvement, etc. are all relatively novel. A number of companies followed the example of a leading computer manufacturer in introducing a variety of physical artefacts in an attempt to create a new culture.

However, we have come across very little evidence of companies going much beyond the single status car-park or newly painted workshops, perhaps to Matsushita's human-centred scenario, where people are seen as the most creative and critical resource.

CIM, Skills and Training

While prevailing structures of control and hierarchy influenced the kind of work organisation experiments companies could try, the problems of skills shortages were equally problematic. The homogeneous job structure in Sweden, in part depended on the availability of highly qualified production workers. In the United Kingdom, some skills were simply not available such as software engineering skills, while other engineering or technical skills were either in short supply, unwilling to work on the shop floor or working in other sectors. The implication of the above is to increase the time and cost of implementing more appropriate work structures in Britain, with wider questions about the role of the Government and the educational establishment.

The question of skills and training is typically reduced to technical competence for system users, but all of our research has pointed up wider shortcomings. In terms of technical skills, most companies give the bare minimum to those most immediately affected; there is a paucity of technical competence among senior managers coupled with a lack of interest which has consistently undermined any strategic fit between manufacturing and business needs. Technological development has typically been incremental and *ad hoc*, usually resulting from the operational priorities

and technical preferences of the various middle managers.

But as we have mentioned above, the immediate challenge of these systems is as much organisational as technical. There is a correspondingly massive need for re-education and support to enable people to negotiate across these changing boundaries and think and work in a more problem-solving and reflective manner. Although a number of companies had experimented with non-technical training and education, it tended to be very limited and the majority of firms did not even bother with anything like interpersonal or negotiating skills.

Conclusion

To summarise, empirical evidence suggests that the trend towards computer-integrated manufacturing reinforces the crucial importance of human and organisational factors.

There is a growing need for organisational integration, in which traditional departmental boundaries and management hierarchies are being re-negotiated, changed or broken down; and where skills are being extended and or re-deployed. Our research to date has shown a range of possible organizational configurations for different integrated systems in different manufacturing environments. The immediate conclusion is that technology is only one shaping factor and that manufacturing strategy should be bounded by local conditions.

In the longer term we need to continue our assessments of the experiences gained so far, to improve our classification of organisational and cultural dimensions in order to extend our understanding of their strategic relationship with technical systems and provide commercially relevant guidance to individual companies.

WORK IN THE FACTORY OF THE FUTURE — IS COMPUTER-INTEGRATED MANUFACTURING A MIRAGE?

by Karl H. Ebel, Industrial Activities Branch, International Labour Office, Geneva, Switzerland

Introduction

There is a widening circle of opinion supported by case studies and research suggesting that industry is at the threshold of a new era in manufacturing. It is often believed that computer-integrated manufacturing (CIM) will transform the world of work beyond recognition. However, there are also many voices and evidence which tell a cautionary tale of failures in the wake of the introduction of this new technology, although failures are seldom advertised because they affect the image of companies. Has the CIM concept really the potential for far-reaching qualitative changes in manufacturing and what can we reasonably expect to happen to the men and women employed in manufacturing? What will be the role of the human factor in the "factory of the future?"

There is no generally accepted definition of CIM. It usually denotes the computer control of the entire production process from design and manufacturing to product delivery. It comprises computer-aided design (CAD), computer-aided planning (CAP), computer-aided manufacturing (CAM) and computer-aided quality assurance (CAQ). These functions and the subfunctions in each area are parts of a system and are fully integrated through computer networks and have access to a unified data base. CIM is thus essentially about organising and controlling manufacturing of components and assemblies as logically and flexibly as possible and mastering and co-ordinating the corresponding flow of data and information. It aims at optimising the use of equipment, decreasing lead time and inventories, high product quality and lower unit costs. The synergies created through integration are expected to lead to cost reductions, higher productivity, and rapid adjustment of product quantity and quality and product variations, as well as delivery times to demand in competitive national and international markets. It appears to offer an opportunity to keep up with shorter product life-cycles and to eliminate much waste.

The concept seems rational, sensible and appeals to the tidy mind. It satisfies the quest of the engineer to

create order out of chaos. It assures and comforts the manager looking for efficient means to control the production process. Why is it then that the realisation of projects runs into much difficulty in practice? Are expectations too high? Even if allowance is made for the fact that CIM can only be introduced step by step, that it requires much computing power and the mastering of complex system architectures and software developments, that different production processes need varying CIM systems (i.e. they must be tailor-made) and that "Rome was not built in a day," it is by now obvious that the initial optimism of many automation equipment and system suppliers, engineering researchers and management strategists is not matched by the practical results achieved so far. The "factory of the future" as described by CIM advocates of the engineering profession remains largely a figment of the imagination despite some science-fiction type realisations. And even staunch technocrats readily admit that industry is far removed from realising the full potential of CIM, although partial solutions such as flexible manufacturing systems, automatic materials handling, computer-aided design, computer-numerical control of machine tools (CNC) have made much promising headway. "Islands of automation" have thus been created in many plants, but linking them is clearly not an easy task. Some CIM systems have been set up as demonstration or pilot projects and serve to learn about this new approach to manufacturing, but they are usually very costly and isolated experiments outside the real world of production. The installation of operational CIM systems in industry is in inverse proportion to the talk about it. Should we, therefore, regard CIM as an impasse, a fading fad or a technocrat's pipe-dream of manufacturing paradise?

As experience in this field accumulates through trial and error as well as failures and successes, and as different schools of thought try to impose their particular vision of the "factory of the future" it becomes increasingly clear that there are various dimensions to the problem. They are of a socio-economic, technical, managerial and human nature and they are partly rooted in industrial history.

The socio-economic perspective

The CIM concept has evolved in the highly industrialised countries characterised by significant capital accumulation and high labour cost as well as a solid and wide scientific and technological base, and a developed social and economic infrastructure. It owes its birth to rapid advances in computer and information technology. Pilot projects and accompanying research to put the concept into practice in manufacturing are concentrated in Japan and the United States and some industrially advanced European countries. However, there are considerable differences in the approaches chosen which tend to be a response to the specific socio-economic situation, the industrial traditions and the factor endowment of the various countries and individual enterprises.

These varying approaches may be typified as the "technocentric" and the "human-centred" approaches. No industrial society has the monopoly of one or the other and they co-exist, although one or the other tendency may prevail. The analysis below which only points out the main features of these approaches and neglects the historic roots needs to be seen in this perspective.

In the United States, the so-called "technocentric" approach tends to dominate in its purest form. It has often served as a model in other countries.¹ It denotes an attempt to gradually reduce human intervention in the production process to a minimum and to conceive systems flexible enough to react rapidly to changing market demand for high-quality products. Workers and technicians on the shop-floor are sometimes seen as unpredictable, troublesome and unreliable elements, potentially disturbing the production and information flow which is best centrally controlled through computers. The "unmanned factory" is the ultimate goal. It is the extreme division of labour reaching its paroxysm as subdivided and simplified tasks executed by a mass of low-skilled labour are progressively taken over by increasingly flexible intelligent and versatile industrial robots and machine systems communicating among each other via networks and computers.

Only a residual role is assigned to workers as their skills are supposed to be gradually and progressively embodied in the machines. It is hoped that this approach will stop the ongoing erosion of production know-how and regain lost superiority of US-style manufacturing and competitiveness in the global market-place. Much capital and sophisticated technology are expected to overcome a deep-seated structural problem: the decreasing competitiveness of

American manufacturing in its home market and abroad. It has been called the "moonshot" approach. Since US manufacturers produce for a large and homogeneous home market, they can concentrate on high volume products and relatively large batches in component manufacturing. The ensuing production process is relatively inflexible even though flexible manufacturing systems and machining cells are used. The central engineering challenge is thought to be arriving at continuous flow production of large varieties of products and components without much work-in-process, i.e. without idling capital. This would ensure high productivity and adequate returns. The human factor plays a minor role in this equation. This is a late vindication of Taylorism or Fordism which was based on the principles and management methods of using vast pools of unskilled and semi-skilled labour. The increasingly sophisticated machinery is thought to make most labour dispensable. Traditionally adversarial industrial relations and little commitment and loyalty of the workforce reinforce this attitude. The technical office manned by professional engineers and technicians becomes increasingly the repository of production know-how to the detriment of production workers.

This approach carried to its extreme has proven not to work very well or only at excessively high cost. It has, for instance, been found that flexible manufacturing systems installed in the United States often performed worse than conventional technology. The relevance of the technocentric approach for the future of manufacturing seems, therefore, questionable.² It may be a dead-end because of an essential flaw: there is mounting evidence that the type of flexible automation which forms the core of CIM systems will only work and remain operational when manned by highly qualified and motivated workers who can cope with the relatively frequent breakdowns of such complex and sophisticated equipment and with software problems. In fact, there are persistent complaints that the specific skills needed for high-tech manufacturing are scarce or simply not available. If there is a lack or shortage of committed skilled and thoroughly trained staff, systems tend to perform far below their potential capacity. Inadequate performance of such sophisticated installations appears to be the rule rather than the exception. At any rate, there is generally a long learning and running-in period with uncertain future returns as a result of excessive reliance on unproven technology.

The Japanese approach to CIM is driven by a different rationale. Companies introducing advanced and flexible automation systems can rely on a highly qualified, versatile and loyal workforce, and do so.

Instead of progressing in the technological field by giant leaps they prefer incremental improvements of the production process and of quality, often enough initiated by motivated engineers, technicians and workers on the shop-floor. The wide adoption of the quality circle movement is only one manifestation. Emphasis is on product quality and production scheduling (i.e. just-in-time production and electronic ordering of materials and components). Compared with the outstanding manufacturing skills manifesting themselves in the wide application of industrial robots, the integration of the information flow through computers is relatively less developed due to gaps and difficulties in software development. The most flexible element in the system is, in fact, the people who make it work. Moreover, most companies operating such systems tend to serve large local and export markets and therefore produce relatively large series, although the flexibility of the equipment is utilised to a greater extent than in American manufacturing thanks to the highly qualified workforce. The strength of this approach shows in diversified high-quality mass production. It is facilitated by a co-operative industrial relations system.

Manufacturers catering for relatively small, heterogeneous or specialised internal or export markets demanding high-quality components and customised products, as is largely the case in Europe, have been inclined to rely on another strategy in the introduction of CIM. In view of the high investments required and the often limited capital base they usually opt for a cautious, pragmatic and gradual approach. The panoply of CIM is adopted with restraint. The skilled and highly skilled craftsman and technician have mostly remained the centre-piece of manufacturing. While Taylorism had made some inroads in European manufacturing, particularly in the automobile and consumer durables industries, it never replaced skill-based production in medium- and small-scale enterprises in the capital goods sector where division of labour is only applicable to a limited extent. Such enterprises competing in narrow markets or occupying market niches always had to be flexible and innovative to survive. The new computerised flexible and integrated automation equipment is primarily seen as a more perfected tool in the hands of a skilled and versatile workforce serving to enhance existing know-how, to obtain greater flexibility, higher productivity, better quality and shorter delivery time. It is not regarded as a panacea to all production problems, but as helpful in gaining a market share. Such enterprises also tend to make a sustained effort to retrain their staff. Also, a lesser division of work allows the allocation of greater and wider responsibility to workers according to their

qualifications and consequently more flexible forms of managerial control and organisation, including team-work and imaginative applications of CIM using available skills.³

There are only vague estimates of the potential economic benefits of CIM. They are usually based on a few cases and stem from equipment vendors or research into limited applications. They are suspect in so far as business accounting methods in use do not permit – or at the best approximately so – to calculate the real returns of such investment. The following indications are therefore given with due reservation and should only serve as a basic orientation.

Thus, CIM is expected to lead to a 10 per cent rise in output, 5 to 20 per cent reduction in personnel costs and 10 to 15 per cent lower production costs. Inventories could be reduced by 20 per cent, scrap by 10 per cent and order lead times by 50 per cent.⁴ Another estimate assumes the potential overall cost reduction to be 5 to 10 per cent, i.e. more than the profit margin of most companies; and points out that CIM mainly gets rid of "hidden" costs and overheads, e.g. accumulation of work-in-process, idle machine time.⁵ There are also more indirect benefits such as shorter product development cycles and accelerated production of prototypes which help to maintain or improve market position. The time-span in which such economic benefits could materialise is not specified.

All investigations tend to concur that the actual saving in labour cost is marginal when considering that the latter normally ranges between 5 and 15 per cent of total product cost. CIM just signifies that there will be less but better remunerated highly skilled labour. Such savings do not offset the higher capital cost. It has been suggested that the reduction of excess stocks and work-in-process could potentially finance all reasonable investment in CIM.⁶

There is encouraging evidence that in general the aggregate level of employment in industrial societies is relatively little affected by the introduction of new technologies. The long-term trend of a fall in manufacturing employment observed in industrialised countries certainly continues and technological innovation is a contributing factor primarily eliminating unskilled work. However, on the whole, job displacement and redeployment of workers in the innovation and rationalisation process appear to balance, and where technological change goes along with strong economic growth, expansion of markets and investment, it even tends to induce positive

employment effects through the revitalisation of the economy. Japan's technology drive and growth pattern is a case in point. However, it would certainly be vain to pin exaggerated hopes on the introduction of CIM and other high technology and their spin-offs as an employment creation device. "Reindustrialisation through high technology" is certainly a misleading concept.⁷ Only a very small proportion of the labour force of the highly industrialised countries – some 2 to 5 per cent – are engaged in this advanced sector, and this proportion will rise only slowly, if at all, if past trends and experience are any guide.

The technical perspective

CIM is many things to many people. Enterprises have to seek their own solutions to the multitude of technical problems in response to their specific requirements. Depending on the complexities of the manufacturing process and the existing organisation pattern they may well be formidable. Existing model solutions are not generally applicable and only show that integration is feasible to a large extent and under specific circumstances – though often at a high price.

It is, therefore, useful to keep in mind what can be gleaned from various studies of CIM introduction about the state of the art.

There are first of all a number of technical shortcomings. A great deal of research and development effort goes into eliminating such technical bottlenecks hindering a wider application of CIM. Considerable progress is being made on a large front and, *a priori*, one cannot say that remaining problems are insoluble. However, there is still many a hard nut to crack and it is not sure when and at what cost effective solutions will be found.

The linking of a wide variety of numerically controlled machine tools and industrial robots, process control computers, automatic transport and storage facilities, quality assurance, design and production planning functions and management information systems through networks is the technical rationale of CIM. So far, the different subsystems of CIM such as CAD, CAM, CAP, etc., have been treated as isolated functions with their own requirements, logic and software. There are many partial solutions to bridging these functions. They have helped to bring about "islands of automation" in factories. Truly integrated large systems, comprising all functions of designing, manufacturing and assembling products with a great number of components do not exist yet.

Networking of systems is mostly in its initial stages. The development of computer software for such tasks is painstaking. The general adoption of standards which are vital for linking computer hardware and automation equipment of various makes is lagging behind. As a matter of fact, there are constant complaints about the proliferation of proprietary operating systems, communication options and control programmes. The existing chaos holds back networking as manufacturers hesitate to commit themselves. It also increases costs. Vendors and users of flexible automation equipment are painfully aware of this situation. General Motors, as one of the largest clients, has therefore pioneered an industry-wide standard – the manufacturing automation protocol (MAP) for the linking of inventory control, robotics, CNC machinery and quality control and will only buy equipment conforming to these standards. The company has recently agreed with the aircraft manufacturer BOEING which uses the technical office protocol (TOP) to make the two systems compatible. TOP is largely complementary to MAP. These plans have aroused some controversy. These systems have been criticised for being too slow and exclusive, and for not tying in with industrial robotics. They are tinged with the image of company proprietary standards. The International Standards Organisation has fixed itself a more ambitious objective; it promotes the Open-Systems Interconnection (OSI) which is to enable all computer systems to communicate with each other. However, OSI also encounters delays and acceptance problems.⁸ It appears that a great deal of research is still needed to arrive at satisfactory world-wide standards.

Compatibility of equipment and systems is certainly a crucial problem, but there are still others. Much information required in the production process is not suitable for coding, computer processing and transmission. This means that available data are not always complete or reliable. However, full integration of the production process means that it must be predictable. Stringent procedures are required which have to be formalised and cover process planning, tool supply, production planning and logistics. Such strict procedures are, of course, the antithesis of flexibility, but they are necessary because robots can neither think nor anticipate.

Further problem areas are unreliable software and automation equipment, rudimentary sensory abilities of industrial robots, poor data quality and accessibility. The need for constant updating of data bases is another drawback. The result of such combined difficulties is that systems are vulnerable and

break down frequently, often more than one-third of the available time.

It might be added that optimal CIM requires complete real time data processing. However, current computer-aided manufacturing (CAM) systems process about 85 to 95 per cent of data by batches which is considered insufficient.⁹

CIM is praised for its flexibility which is true up to a point, in particular when it comes to machining of families of parts. On the other hand, it is 'atively inflexible with respect to alteration of batches and when process innovation is contemplated. In fact, every change of a customer's order or equipment, tools or materials has first to be modelled in the computer system.

There are some technical remedies on their way. The development of fault-tolerant computer systems is making progress. The sensory abilities of robots are constantly improving. Greater data storage density and processing speed of computers will help to build more "intelligent" systems. Moreover, some promising developments in "artificial intelligence" and expert systems may well help to make systems more tolerant and responsive to faults. Expert systems are already being used in standardised procedures and routine checking, and are beginning to play a role in maintenance, fault diagnostics, production control, quality assurance, planning, scheduling, design, notably computer-aided design (CAD), and support software development and training. Nevertheless, such systems have their limitations. They embody knowledge extracted from experts and reason according to rules, but there are limitations to formalising human abilities, sensorial experiences as well as open and complex industrial processes. Also common-sense knowledge is not programmable, nor do expert systems have intuition or practice associative thinking. They can therefore support, but not replace, human decision-making.

Another way of minimising technical problems is the initial design of products in such a way that they can be processed and assembled with the available flexible automated equipment. This means simplification and reducing the number of components, streamlining assembly operations and generally taking into account the ability of machines and robots at the design stage.

The managerial and organisational perspective

There are different management attitudes on how to cope with CIM. In part they are a mirror image of the national idiosyncracies and different industrial histories evoked above. Thus the technocentric approach results in management strategies which neglect or underrate the human factor in production. It is frequently aggravated by short-term profit maximisation considerations which are the curse of technology planning and management. The introduction of CIM requires long-term strategic thinking. From the managerial point of view it is fundamentally an organisational quandary. It is about creating order out of chaos. Equipment needs to be carefully selected and compatibility ensured. However, the essential question is how to reshape existing production processes, how to alter organisational boundaries and to make them permeable. This requires redesigning the information and data flow. The difficulties of actually doing this in existing organisations, to make them more effective and efficient should not be underestimated.

CIM introduction may well act as an antidote to poor management practices. This is when the human factor comes in. Industrial case studies and experience accumulated so far clearly indicate that a pragmatic management approach advancing step by step, building up the skill, responsibility and motivation of the workforce, investing in people operating the systems and relying on the human factor in making them flexible, has consistently paid off best.

The conviction that this is really so seems to be lacking in many management circles, otherwise the revalorisation of the human factor would be pursued more systematically and consistently. At any rate, it has been found that in general CIM is not primarily introduced "to humanise work." The motives and expectations of management mostly relate to inventory reduction, more transparency of the organisation, reduction of lead time, greater adherence to deadlines, saving of personnel, greater marketing flexibility, increased capacity use, higher product quality or keeping up with technological developments, all leading to higher productivity. Better working conditions tend to be a very low priority and a rather accidental by-product.¹⁰ In fact, working conditions may even be neglected or worsen, particularly when automated machinery is used to enforce an accelerated pace of work, where only residual tasks are entrusted to workers or when stressful situations are engendered by computerisation.

A management style allowing more autonomy of production personnel may well mean a break with entrenched principles and thus be conceived as a threat to vested interests and the power structure in an organisation. It is hardly surprising that such clashes are avoided almost at any price. It is, in fact, possible to switch to new technology without making fundamental organisational changes, and to keep compartmentalisation and established hierarchies in place. Information technologies may serve to institutionalise and even reinforce ineffective and counterproductive management practices such as excessive centralisation of decision-making or abusive monitoring of individuals if the powers that be manage to fend off restructuring. This is, of course, costly and leads to mediocre results while it prolongs the life of organisational dinosaurs. It signifies the defeat of the primary purpose of CIM, i.e. the integration of all functions. Such integration requires "vertical and horizontal synchronisation of departments, people, machinery and processes in the flow of information and material."¹¹ In such a system the necessary flexibility can be achieved through decentralisation of information and responsibility within a given framework in order to achieve small and fast control loops. This enables the production system to respond rapidly to market demand, particularly in the case of many product options.

If progress is to be made in the effective introduction of CIM a clear strategy is needed endorsed by senior management and promoted by the rank and file. Nothing much can be done without the consistent backing of top management but the stumbling block can be middle-management which stands to lose influence when hierarchies tumble and all required information is available "on-line" without intermediary to all participants in the production process. This emphasises the need for top-level technology management, a function frequently neglected as legal, financial and marketing aspects tend to dominate decision-making at the top. It is not enough to let middle-management acquire technology and then to do crisis management at the top when bottlenecks occur in the organisation or qualifications are lacking.

Some have traced existing problems to the lack of managerial competence.¹² Managers' knowledge of advanced manufacturing systems is frequently limited even when they have had a technical education or are professional engineers. Manufacturing technology and, more in particular, information technology, is moving fast. Professional knowledge and experience once acquired becomes rapidly obsolete without continuing exposure to shop-floor experience. Thus,

potential users of automation equipment fear that they cannot muster and constantly update the necessary know-how. They often depend on outside consultants and equipment suppliers. They naturally tread carefully in unknown territory and avoid incalculable risks.

As capital requirements for the implementation of CIM are high, managers are under pressure to justify such expenditures. By the standards of a short-term return-on-investment (ROI) approach the financial feasibility of CIM projects is mostly doubtful despite the hypothetical economic advantages outlined above. In fact, there are no generally agreed methods for doing reliable cost-benefit analyses of CIM. As a matter of fact, the cost of full CIM implementation is often considered to be prohibitive despite the fact that most equipment to build such plants may be available. It is also feared that the systems are inefficient to use and expensive to maintain because technical change would constantly require the replacement of parts of the system, by definition not an easy job in an integrated system.

To this should be added that in present flexible manufacturing systems fixed costs constitute about 70 per cent of the total outlay. This is an indication of the high risks which management takes when installing CIM.

There is, of course, also the more positive side of the coin: risks are balanced by opportunities if the predicted economic benefits of CIM materialise. Moreover, in the coming years capital requirements are bound to descend because cheaper systems are being put on the market. It has also been estimated that CIM plants could break even at 30 to 35 per cent of capacity use as against 65 to 70 per cent in the case of conventional plants. Also the planning of CIM and at least a partial implementation could help management to improve the organisation of the production process and the flow of communication.

But costs are not the only element to be considered in making strategic decisions about the introduction of CIM. A responsible and forward-looking management may well conclude that it cannot afford to be left behind in the technology race and that research and development expenditures for process technology must be met and that investment in CIM is required to remain competitive in the long run. Clearly, much depends on the specific situation of the enterprise.

If the strategic decision to implement CIM is made, management's essential task in implementing CIM is

overcoming organisational resistance to change starting from the shop-floor through all layers of the organisation. The streamlining of an organisation and making it fit for CIM may be a considerable challenge but may be well worth it. The findings of a variety of surveys concur, in so far as those manufacturers who have introduced advanced manufacturing systems attribute between 40 and 70 per cent of the total improvement achieved to organisational changes. In other words, the main benefit does not necessarily stem from sophisticated and integrated technology but from the reform of management and production practices and from a more transparent and efficient organisation.¹³

The human and social perspective

The indispensable human factor

If we admit that a technocentric approach to CIM would be inefficient and counterproductive it follows that the key role of the human factor must be recognised. The art is to assign a really effective function to it and to give people an opportunity to make full use of their knowledge, capabilities and skills, and to help them master the production process. This means putting them in appropriately designed jobs and workplaces, having adequate man/machine interfaces, making the production process transparent, setting up suitable work organisation as well as providing the necessary training.

It is important to look at the potential weaknesses and strengths of the human factor in a CIM environment. Human beings involved in the production process are error-prone, particularly under physical or psychic stress. Noise or bad lighting may lead to fatigue. The error rate also grows with information overload. Survey findings show that 70 to 90 per cent of the failures of technical systems are due to faulty human intervention or system design. Human beings do not always work with full concentration, come to wrong conclusions, make mistakes or do not act when they should. Their operating behaviour is relatively unpredictable. Is this sufficient reason to try to banish people from the production process?

There is clearly a wide range of tasks and functions which are best done by machines, industrial robots and computers. This range is widening constantly and more and more manual operations are taken over by machines. The improvement of sensors and actuators makes robots and other production equipment more versatile, rapid, and exact. Some jobs can actually be done infinitely more efficiently and reliably by information systems and computers than by human

beings. This is particularly true for routine functions such as data collection and their statistical analysis as well as many surveying and control functions which is the basis for automatic process and quality control in production. It can be envisaged that the execution of increasing numbers of specialised functions can be transferred to machines and computers. We are therefore faced with a growing complexity of such technical systems.

However, as such systems become more complex they also tend to be less fail-safe. In fact, they break down frequently, causing high cost. They can be repaired and perfected but this requires skilled human intervention. In such an event workers responsible for the operation have to make choices and decisions which no technical system can make for them. Often quick intervention is required which is based on knowledge and experience and takes into account the limits of the system. The human being despite its weaknesses is, thus, indispensable for an optimal and efficient use of automated equipment. The qualified, motivated and experienced worker familiar with the system can cope with uncertainty and is able to assess situations, to find and interpret faults rapidly and correct them. Judgement supported by technical knowledge and experience, understanding of systems and common sense are qualities which cannot be replaced by computers or artificial intelligence in the foreseeable future. In CIM systems machines and computers may well take over most routine and physical tasks but they do not dispense the people involved from thinking, critical decision-making and responsibility.

The design of CIM systems

As the human factor cannot be replaced it is crucial that CIM systems are designed and planned in such a way that people involved can do their job in optimal conditions and can really apply their empirical knowledge. In the first place this means that they must not be made totally and helplessly dependent on the system. This might have serious consequences when system errors cannot be corrected in good time. Also, such dependence limits initiative, improvisation and creativity, and fosters submission to routine which in turn makes the systems, and consequently the enterprise, vulnerable. Overdependence on systems and machines has not only provoked disasters in nuclear and chemical industries, it is also the cause of perhaps less spectacular, but none the less very costly failures in automated production. Workers in CIM systems designed to make use of the human factor should be able to intervene in the production process to optimise it. This signifies that the system must

allow shop-floor programming of CNC equipment on the basis of indications provided and discussed with the design office. The implementation of such organisational principles presupposes the availability of appropriate man machine interfaces and software. An example of what can be done is the use of a portable electronic sketch pad which could help to overcome the notorious divorce of designers from the realities and constraints of the production process which has been accentuated by computer-aided design. Such a device will help them to discuss design ideas with shop-floor personnel.¹⁴

A further problem to be considered is that the physical distance between the personnel operating or supervising the equipment and the process tends to widen. Much visual and manual control is replaced by sensors which transmit data to screens and data bases. The worker is faced with control data at his workstation, but loses direct touch with the process. Often it can only be monitored from a control room. It has been found that such distance from the process may make quick reaction and the correction or compensation of system faults more difficult because warnings emitted by the system can be misinterpreted or neglected and workers lose the "feeling" for the process. This means that the process must be designed transparently, be comprehensible and sufficiently accessible without hazards in order to allow the required or desirable intervention. Some research has been done on the significance and role of empirical knowledge of machines and materials which experienced skilled workers possess. It appears that they develop a feeling, almost a sixth sense, telling them what is wrong with a machine and how it works best. This capability is precious and should not be underestimated for the smooth running of advanced manufacturing systems.¹⁵

In the technocentric approach to CIM there is clearly a danger that most production knowledge will be incorporated in the computer and expert systems without giving workers sufficient opportunity to exercise their skills which would waste away because they are no longer used. However, this would make production systems very unwieldy and vulnerable and their formalism would cause considerable constraints. Moreover, the human knowledge base of enterprises could be eroded to such an extent that their future is put in jeopardy. This is too high a price to pay for enterprises which depend on the qualification, skill and adaptability of their workforce.

Moreover, there are signs that the technocentric approach may cause the disaffection of the workforce. Research findings in the United States suggest that

workers in high technology industries are less satisfied than other manufacturing workers due to more rigid rules, stricter discipline, and closer supervision and monitoring.¹⁶ Apparently such disaffection has been noted particularly in the case of production workers who felt threatened by deskilling. This may well be related to the fact that management has a tendency to leave the trouble-shooting and maintenance and repair of advanced systems to specialised services without involving the operators of the equipment. It is probably significant that this neglect of shop-floor skills has led to a great increase in production down-time.¹⁷ The way out is obviously to entrust as much responsibility for maintenance as possible to suitably qualified workers on the shop-floor.

The practical problems of taking all these aspects into account in designing CIM systems and of making optimal use of the human factor must not be underrated even when such human-centred systems are recognised as superior. A multidisciplinary approach is required which is by no means easy to organise. Managers and engineers designing the system will have to be committed to such an approach and should associate ergonomists, training specialists and social scientists. There are few tried methods since the technocentric approach neglecting ergonomics and social concerns prevails up to now. Often engineers and ergonomists tend to be at cross purposes. This is a field which needs further exploration.¹⁸

Skill requirements for CIM

The above observations imply that the skill level of shop-floor workers is going to increase despite some skills becoming obsolete and that division of labour will regress. CIM requires versatile craftsmen and technicians, computer and software experts, mechanical and communications engineers and, in general, people who understand production methods and the system and are capable of coping with a great deal of technical information and are able to take decisions on the spot. There is little room for unskilled workers such as assemblers, labourers, machine loaders, transport workers, etc. CIM also makes clerical workers redundant, that is those who are occupied with ordering parts and materials and scheduling the workload of machines.

Also managerial jobs at the middle level are bound to be changed or diminished in CIM systems which entail a general dissemination and free flow of information. There tend to be fewer hierarchical levels and demarcation lines, and there are fewer co-ordinating tasks. Emphasis is more on planning,

anticipating problems, team-work and interaction and much less on formal communications, and giving instructions. Excessive monitoring of workers which is technically possible is best avoided because it can antagonise the very people needed to man the systems. It is a new world for team leadership in CIM which requires a combination of human, conceptual and technical skills in managers.¹⁹

New types of work organisation

As many specialised jobs are abolished due to a lesser division of labour, work organisation tends towards group work. In such relatively autonomous groups members execute complementary tasks and must be versatile as varying tasks are allocated with the objective of keeping the system functioning smoothly. Group members must be able to communicate beyond narrow technical boundaries and to co-operate. They also have a certain autonomy in the choice of tasks and detailed planning. Thus existing qualifications are better used and mutual coaching takes place. If properly organised, greater job satisfaction is the result.

However, such participative work organisation is by no means an automatic outcome of the introduction of CIM. Management must consciously seek to overcome outdated, demotivating and unsuitable hierarchical forms of organisation which means the shedding of old power relationships — often a painful process fraught with pitfalls. Vested interests in the status quo are usually very strong. However, it should be some comfort to management deciding to base CIM on group technology that production is usually less capital-intensive since it is less computerised and requires less expensive software because many decisions are taken on the shop-floor which also helps to make it flexible. Moreover, existing qualifications of the workforce can normally be used and few new ones are required. There is also a reduction of through-put-time.²⁰

Some concern has been expressed that CIM will lead to the social isolation of the relatively few workers left on the shop-floor who remain there to mind the system. In fact, much communication takes place via computer terminals and opportunities for social contacts are diminished. This may well affect individuals and the working atmosphere in plants negatively. In the end such dissatisfaction would have negative consequences for the overall result of the production process. At any rate, system designers need to keep this aspect in mind and provide opportunities for social contact as a contribution to quality of working life.

Hazards in the new working environment

While the new job requirements in CIM systems are becoming better known, there is much uncertainty about new occupational safety and health hazards. It stands to reason that physical risks are diminished because less workers are in direct contact with production equipment and most production takes place without direct human intervention. On the other hand, there is usually a higher pace of work as well as much shift work which tends to increase fatigue and the accident rate. It has been found that work at computer terminals can be very stressful indeed, particularly in the case of computer-aided design.

A potentially very serious problem is that apparently an increasing number of psychosomatic illnesses may be caused by the new automated systems. Workers confronted with the new expensive and complex equipment often do not feel up to it and feel powerless. They cannot intervene in the process while being responsible for running it. The combination of high responsibility and insufficient qualifications to master the job at hand or to intervene is extremely stressful. This may be aggravated by frequent breakdowns which have to be repaired under time pressure. The resulting permanent stress can lead to nervous and physical disorders and is said to affect a disproportionate number of workers in advanced manufacturing systems. Training and ergonomically designed workplaces may help. However, it is probably more important that system designers do not place excessive demands on system users and maintenance staff or do the opposite and make jobs undemanding and monotonous which would also cause stress.

Another cause for concern is the fact that work becomes more static and jobs need more brainpower than muscle. Physical activity is much reduced as machines and robots take over materials and components handling. Such reduced physical activity has been identified as a significant threat to health. Countermeasures may well be needed.

A further cause of fatigue and stress is the ineptness of much computer software. Much of it is not user-friendly and is remote from actual workplace requirements. This can make man/machine interaction very cumbersome. "Cognitive" ergonomics addresses these problems. However, this is a relatively new science and improvements in software design taking into account research findings are only slowly forthcoming.

System designers who usually have an exclusively technical or scientific background tend to overlook such considerations in the planning stage of installations. However, this is the time when preventive measures have to be taken. Planning and investment costs are usually only slightly increased. It is much more costly to rectify ergonomic mistakes once a system is installed and is therefore mostly not done.²¹

The principal objective should be the creation of humane working conditions, for only workers treated primarily as responsible human beings will commit themselves to company goals. A definition of humane work which deserves attention in this context is the following:

Work is called humane if it does not damage the psycho-physical health of the worker, does not, or only temporarily, impair his psycho-social well-being, meets his requirements and qualifications, allows him to exercise individual and/or collective control over working conditions and systems of work, and is able to contribute to the development of his personality in activating his potentials and furthering his competences.²²

The preparation of the workforce for CIM

If people are the key to successful CIM, much hinges on their preparation for the new systems. In all industrialised countries there is a shortage of professional, technical and managerial personnel able and qualified to mastermind the implementation of CIM. The major constraint is not only the lack of adequate computer hardware or software. At the shop-floor level also the necessary skills are mostly in short supply. The recruitment difficulties of enterprises and the high initial salaries paid to capable young engineers and technicians in this field are a case in point. This skill shortage may well explain many of the failures of systems reported hitherto. Often management appears to have only a hazy idea of where they are going. Also, workers' representatives are seldom aware of the intricacies and possible social consequences of CIM.

There is no easy way out. One of the answers is systematic training and further training of the workforce based on a specifically designed training strategy endorsed by management and workers' representatives. Such training is required before the new equipment is installed and will have to emphasise not only specialised technical competence, including computer literacy but, above all, system knowledge; planning; organisational and communication skills;

and group dynamics. It needs to be done mainly by the enterprises themselves in co-operation with system suppliers because CIM systems are tailor-made for the specific requirements of enterprises and training institutes rarely have the expertise in leading edge technology.

Another answer may well be the widest possible use of expert advice in the planning stage of CIM and an open discussion of alternatives among all concerned. This includes the workers' representatives who far too often are faced with a *fait accompli*. A thorough discussion of the economic, technical, organisational, and manpower parameters and of the objectives of an innovation subsequently facilitates an informed assessment of the social consequences and the negotiation of working conditions. Both management and the workforce usually move into uncharted territory and might as well recognise this.

The impact of CIM on industrial relations

In the real world the transition to CIM systems even when well planned and prepared will rarely proceed without tension and potential, if not open, conflict in organisations. The workforce has good reason to worry since there is plenty of evidence showing that its interests might not be taken sufficiently into account or might simply be neglected. Far too often technology is put before people who then have to cope with it somehow without being properly trained or involved in its choice. Small wonder that systems fail. Workers fear pay losses through less overtime, redundancy, the erosion of promotion prospects and lower manning levels, expropriation of know-how through data bases and expert systems, higher stress through responsibility for expensive capital goods, more strenuous shift work patterns, individual performance monitoring through the computer system, deskilling and generally the unknown, and the stress of the adjustment to new working patterns. This can be, but must not be, the outcome.

With a strategy that puts people first and seeks genuine consultation at all levels, such fears may be overcome and do not have to materialise. The positive aspects of change to the advanced systems and the new opportunities will more easily impose themselves such as safer and less physically taxing jobs, learning and training opportunities, greater responsibility and more interesting assignments, better remuneration, generally better working conditions or greater job security in a more competitive enterprise. It can also bring down the rate of absenteeism. Innovations have, in fact, the potential of influencing industrial relations for the better, if more emphasis is

put on consultation at all levels and less on "the arrogant expertise of technologists."

The positive aspects can only prevail in an atmosphere of social dialogue and good will at the enterprise level. Adversarial industrial relations could easily spell the failure of CIM projects. CIM presupposes a reconciliation of interests of management and workers. The dialogue between social partners is thus essential for product and process innovation, higher productivity and flexibility in manufacturing.

There is indeed evidence that in an adversarial industrial relations atmosphere management resorts to excessive division of labour as a means of restricting the influence of unions. In such circumstances management tends not to entrust blue-collar workers with more autonomy and control (e.g. the programming of NC tools) thus avoiding rules and constraints imposed by collective bargaining agreements. This has the perverse effect that unionisation inhibits skill acquisition by blue-collar workers and their upgrading.²³

The greatest menace to workers' autonomy and to job satisfaction stems from centralised control which also introduces much demotivating rigidity and formal procedures into the production process. Decentralised systems coupled with a maximum of decision-making at the shop-floor level are well suited to small-batch or customised production, tend to enrich jobs and qualifications, cut down machine-down-time through better scheduling and maintenance and, therefore, enhance productivity. They often prove to be economically superior to rigidly centralised systems with excessive division of labour.²⁴

A high degree of consensus and co-operation is indeed required if CIM systems are to work smoothly, which does not exclude a resolute defence of workers' rights and interests. It cannot be overlooked that highly skilled workers and technicians and their representatives in integrated manufacturing are in a strong position and cannot easily be replaced. In fact, enterprises installing such systems depend on the quality and commitment of their workforce. Qualified personnel is needed to maintain the complex and costly equipment and keep the systems working. Advanced manufacturing systems are vulnerable to strikes by a small proportion of their workforce. Responsible management is therefore well advised to seek the social dialogue and collective agreements providing a framework for the operation of the systems. An unorganised workforce kept in check by management prerogatives and arbitrariness, subdued by authoritarian supervision and anti-union policies

could easily be resistant and harmful to CIM. Industrial relations based on mutual confidence and respect would appear to be more conducive to success.²⁵

However, it should not be overlooked that as hierarchical structures change and as middle management is threatened by CIM the role of unions and workers' representatives in enterprises might also be weakened. Autonomous groups of highly qualified staff may feel less in need of union representation and intermediaries *vis-à-vis* management and may have a more direct influence on the determination of their working conditions.

It should be obvious that in enterprises wishing to operate CIM systems the social dialogue cannot be limited to questions of remuneration and benefits. At any rate, exclusively achievement-oriented wage systems may well have to be redesigned as system success or failure and higher productivity generally cannot be attributed to individual machine operators but depends essentially on reduction of down-time of automated equipment. The social dialogue will have to embrace questions and problems related to the implementation of the new technology, such as more flexible working time arrangements, adjusting working conditions to team-work, redeployment, etc.

Employment consequences of CIM

It has already been pointed out that a relatively small percentage of the total manufacturing labour force is working in advanced manufacturing systems and that in this respect not much change is foreseen. The great majority of manufacturing workers will not experience radical change caused by CIM systems in the near future. Nevertheless, it must be expected that CIM will accentuate the already existing labour market segmentation. A core of highly qualified craftsmen, technicians, engineers and professional workers manage and operate such systems and are increasingly indispensable. They are generally well paid and their working conditions are stable thanks to their position as knowledgeable workers and experts, but access to this core is more and more difficult to achieve. Ancillary workers have little opportunity for upward mobility unless they possess or acquire the necessary skills and their conditions of work are also more precarious. This situation may eventually lead to social conflicts.

Research on the promotion of the human factor in CIM systems

It is one thing to identify the features which a CIM

system, taking into account the human factor, should and could have, but it is quite another to design and make such systems acceptable to management and work in practice with an adequate rate of return. In most manufacturing the division of work is still well entrenched and tends to be used as a means of social control. The Taylorist mentality in production management is widespread and resistant and will not disappear from one day to the next, particularly in mass production. A conscious effort is needed to promote the human-centred approach to CIM. As the movement is gaining ground a great variety of research projects have been launched throughout the industrialised world with the objective of developing models and defining the technical, ergonomic, organisational, social and training criteria for such systems.²⁶ This research is sponsored under several national and some international programmes of the European Community²⁷ (e.g. FAST ESPRIT, EUREKA, RACE, COMETT, BRITE), involving a wide range of technical, social science and training research institutes, enterprises and employers' and workers' organisations. Partial results have been reported – some of them encouraging, others less so. Also, contradictory findings are not rare. It is clearly not easy for work science, ergonomics, design and systems engineering to come to grips with the manifold aspects and the complexity of the problems at hand. Interpretations, recommendations and proposed remedies also depend considerably on the point of view and the ideological leanings or ethical principles of researchers as there are few certainties but much wishful thinking. It is obviously too early to assess the impact of such research on industrial practice. However, as the technocentric approach to CIM runs into growing difficulties the opportunities for alternative models necessarily brighten as enterprises may be more willing to give them a try.

There are some hopeful signs. In the United States, the Work in America Institute – a tripartite body – co-operates with a series of large enterprises in the effort to enhance the role of the human factor, recognising its decisive influence on productivity. Only a small minority of enterprises are involved, but it is a beginning.²⁸

The development of design criteria and methods under the ESPRIT project "Human-centred CIM systems," in which representatives of various disciplines of engineering, ergonomics and social science co-operate, looks particularly promising. Eight industrial and academic partners based in Denmark, the Federal Republic of Germany and the United Kingdom are involved.²⁹

Mention should also be made of the promotional activities in this field of the International Federation of Automatic Control (IFAC) whose Committee on Social Effects of Automation makes considerable effort to assess the social impact of control and automation technology and brings together concerned scientists, control engineers, managers, system designers, social scientists, industrial psychologists and specialists of other disciplines from research institutes and industry from a wide range of countries. The committee emphasises the social responsibility of control engineering and aims at the establishment of socially desirable requirements for the development of automated systems, demonstrations of alternatives of design of such systems, the strengthening of links between technologists and social scientists, and the dissemination of knowledge of these topics among the scientific and technical community. It has encouraged a considerable number of projects in which industry has co-operated. It has contributed in no small measure to the germination of the idea of the human-centred approach to CIM, and which is slowly but surely making headway.³⁰

Outlook

At present there is hardly a chance of reconciling divergent views on CIM. Many of its advantages or faults are in the eye of the beholder. However, it is definitely not a panacea for all problems encountered in production as some seem to see it. At any rate, the promised land of total manufacturing integration is still far away, although an increasing number of enterprises appear to be engaged on an evolutionary path towards integration.

By any standard, the introduction of CIM is a risky undertaking. If it is to be successful the manufacturing organisation and product range have to be reviewed and rationalised. The pace of transition would depend on the knowledge, qualifications and abilities of the planning and operating staff.

CIM is a leading edge technology and its introduction requires long-term strategies and possibly forgoing immediate financial benefits. The most essential element in such a strategy is the preparation of the workforce for the impending changes. This means consultation at all levels and a systematic training effort. The neglect of further training of staff is inevitably very costly in terms of machine down-time and scrap production.

All experience accumulated so far speaks for a cautious and incremental approach as the absorptive and learning capacity of the workforce might be

overstretched with negative results. However, the trend towards more manufacturing integration is bound to continue and scientific advances will continue to propose solutions to pending technical problems. However, CIM is most likely to fail where it tries to supplant essential human qualities. The subjugation of people to machines and technical systems is proving more and more counterproductive. Instead, work organisation is needed which enables and motivates people to use their theoretical and empirical knowledge and skills in mastering advanced means of production and operating them efficiently. CIM will only be as good as the people in charge.

Are we heading in the wrong direction? Evidence suggests that the difficulties and complexities of introducing CIM on a large scale were initially underestimated. The technocentric approach aiming at the "manless factory" is now questioned for a very good reason: it has not produced the expected results so far. This is having a sobering effect on the unconditional technocrats. There is probably not just one type of "factory of the future" but many alternative solutions to manufacturing problems.

Will CIM really spell the end of Taylorism? It is definitely too soon to consider Taylorist methods dead

and buried. Such methods will continue to subsist in mass production alongside with dedicated automation and machinery and so will the corresponding hierarchical management structures. However, mass production and market dominance of mass-produced goods are declining in many manufacturing activities. The markets demand differentiated, diversified and customised products. This means small-batch production. CIM, i.e. flexible automation, could do the job if properly conceived.

Integrated manufacturing systems are very vulnerable to disruption. Running them efficiently and to the extent possible round the clock presupposes harmonious industrial relations, for work stoppages, go-slows or other types of resistance stemming from demotivating working conditions can cause major losses. Success of CIM, therefore, presupposes a good understanding and co-operation between management and the workforce and its representatives. While it is certain that the introduction even of well-designed CIM systems will cause tensions, it also offers new opportunities to intensify and improve the social dialogue and to break down barriers - a chance not to be missed.

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PART FOUR

DEVELOPMENTS OF CIM SYSTEMS AND THEIR

SUBSYSTEMS

CIM – THE INTEGRATION ASPECT

by N. MÄRTENSSON, Chalmers University of Technology, Gothenburg, Sweden

1. CIM development background

Computer-integrated manufacturing is the latest powerful manifestation of a continuous development process in manufacturing engineering. It has both a technical and an organizational background. The technical development side has shown a remarkable regularity over the last 25 years (fig. 1).

With about five-year intervals, a new piece of technology has been introduced, tested and approved and has grown to maturity. One may notice that the basic mechanical components, like NC-machines and industrial robots, preceded the basic software components, CAD, CAM, MAP. For one thing this implies that man's imagination driven by software development will immediately face restrictions in the existing physical machines, a fact not always recognized.

Organization of manufacturing to meet new demands, like custom-order and small-batch production, has been a parallel activity, e.g. restructuring from batch production to workpiece flow orientation took place in the 1960s and 1970s. The NC-machines and industrial robots played a central part in this development towards more precise planning and better shop-floor control. In the late 1970s and early 1980s flexible machining cells (FMC) were introduced and also large systems, FMS, were constructed. This development made ultimate use of the machine components to rationalize the physical handling of tools and workpieces, while information transfer was limited. Experience from large systems tended to be discouraging, due to their limited flexibility and availability. The bulk of existing systems are therefore of the cell-type, FMC.

With this now an established technology, it is realized that some effort must be made to connect these cells, often called "islands of automation," to a really flexible and reliable system. This is achieved when the information flow is managed just as efficiently as the flow of workpieces and tools. Thus the introduction of MAP paved the way for real computer integration of manufacturing and we are now enjoying CIM realization in several areas of industry.

Just like FMS ten years ago, the CIM concept has a far-reaching potential for the activities of a factory but the more this potential is achieved, the harder further penetration becomes. This paper highlights a few problems on the road that will be necessary to overcome for integration. In the case of complex manufacturing systems, this reality manifests itself less as a tendency towards deterministic behaviour, the more pronounced the more complex the system is. This makes system control more difficult since unpredictable stochastic events cannot easily be met by pre-programmed actions. A need for heuristic control will arise.

The technical means to meet these new demands may consist of sensor feedback that will give automatic reactions of physical system components, AI-assistance that will facilitate producing necessary manufacturing information, and user-oriented system interfaces that will involve the human operator in decision making and performance improvements to an extent where he will really run the system rather than just watch it running. So, if one would like to predict the development ten years ahead, it is the author's suggestion that adaptive control and later on intelligent interaction between man and system will be the contributions of the 1990s. Some examples of research in this area will now be presented, related to the field of automatic assembly.

Figure 1. Technology diffusion in Sweden

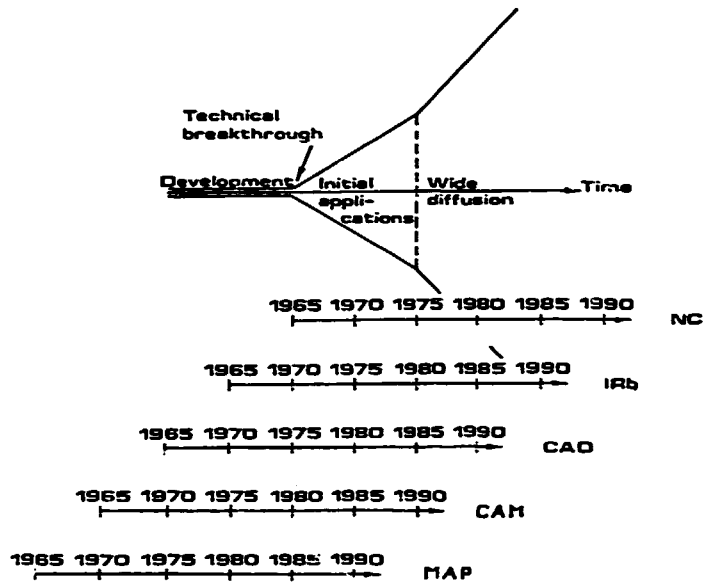


Figure 2. Force-torque control of insertion in assembly

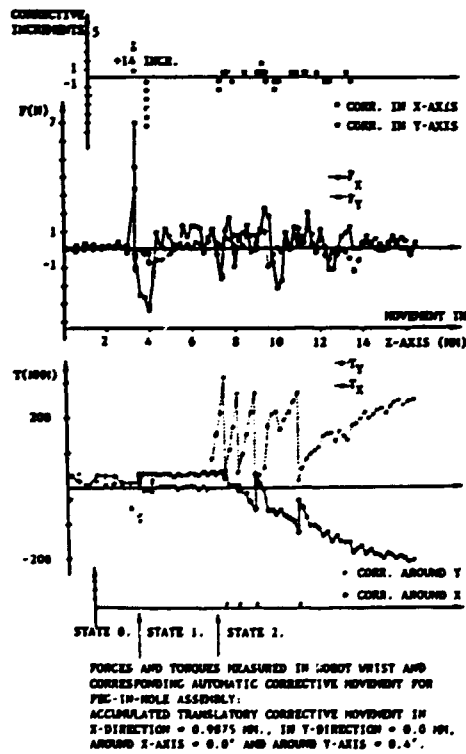
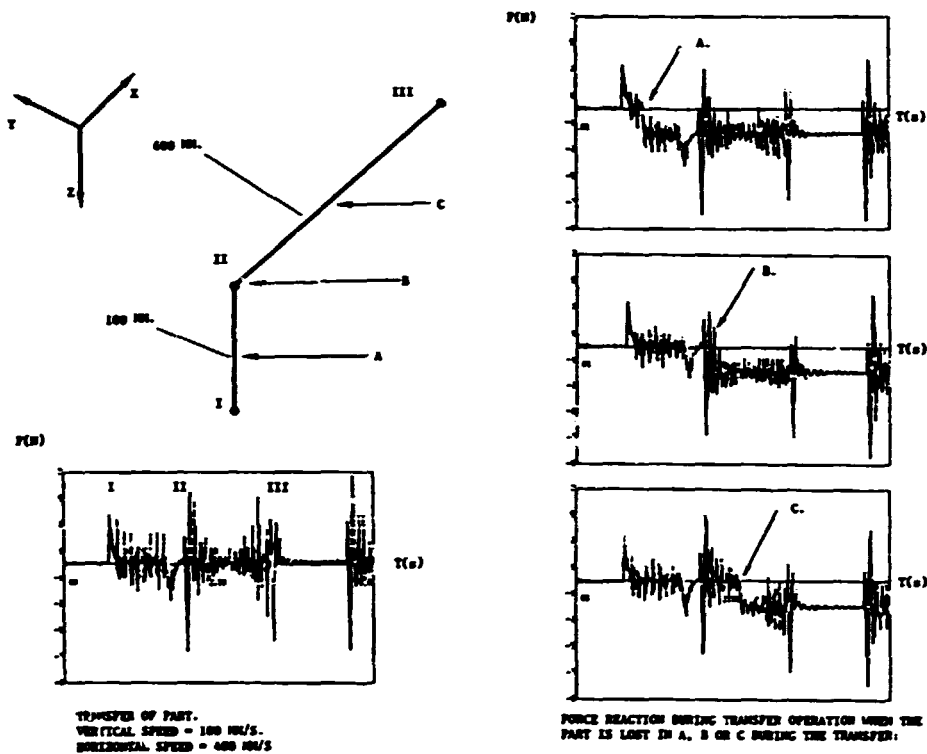


Figure 3. Monitoring a transfer operation



2. Sensor feedback for adaptive control

All parts of a system, be they hardware, software or humans, show tolerances which in complex systems may interfere and create large deviations from predicted behaviour. Sensor-based control is therefore necessary for real-time adjustments of programmed activities. Sensors have three distinct levels of application:

- To make the system more robust by absorbing minor tolerances.
- To increase the system reliability by monitoring large deviations.
- To raise flexibility by reading new information in a largely unknown environment.

In an assembly operation insertion often means positioning within close tolerances, smaller than

e.g. the accuracy in repeatability of an industrial robot. Signal feedback from e.g. a force-torque sensor can be used to control the insertion by minimizing the signal (figure 2) (1).

The same sensor can also be used for monitoring large deviations in other assembly sub-operations, e.g. transferring a part from a pick-up position to an insert position. If the gripper loses the part, there will be a distinctive force reaction (figure 3).

The usability of a particular sensor can thus be mapped in a particular application.

The mapping will show that a single sensor will probably be very good for some sub-operations but rarely able to cover the complete application (figure 4). Therefore a simultaneous use of different sensors can be predicted. To sort out their different

characteristics, there is a need for a general sensor model. This model consists of a specification part and an interaction part.

The specification part might describe:

- What is measurable
- Field of operation
- Accuracy
- Behaviour (e.g. linearity)
- Control possibilities
- Supervision possibilities

The interaction part consists of a software module including sensor data acquisition and process control based on the data. The behaviour of the interaction module depends on a few parameters. Depending on the given parameters, the module can operate in a broad spectrum ranging from continuous control to pure supervision.

Input to the sensor model consists of a steady flow of sensor data (information) during the process, together with the initially given parameters, provided by a superior program, to specify the control strategy. It is desirable to use as few parameters as possible in order to simplify the operation. However, the model loses generality as the number of parameters decreases.

The principle of a force-torque sensor-model interaction part is very simple. It can be described as a force and a torque "co-ordinate system" attached to the sensor, preferably in the tool centre point of the assembly robot. When a force exceeds the limit of a desired force interval, the sensor model starts acting on the robot to obtain the desired state again.

In an experiment with vision and force-torque interaction, the problem was to assemble a shaft into a bore. The bore part position was unknown to the assembly robot and could also change during the

execution. A hand-eye vision system was used to estimate a rough position of the bore, and the force-torque sensor performed the insertion of the shaft and verified the operation (figure 5). The experiment showed that when two or, in the future, more sensors operate together, general parametric sensor models will contribute to an easier implementation.

3. AI-assisted operations sequencing, planning and programming

Introducing a new product or variant in a CIM system will require new programs for executing operations and also for resetting the equipment. For a high-level flexible system this implies a frequent generation of new programs. Since in CIM the product and production information is already stored in databases, it may be better to generate these programs automatically. This includes sequencing, operations planning, control code generation and finally the code execution in the manufacturing system.

To accomplish such a programming system, a hierarchy has to be specified dividing the system into distinct levels according to the division of the assembly problem. This implies specifications of well defined and demarcated, hierarchical abstractions of the assembly problem, ranging from the product model at the top, to the general purpose programming language at the bottom, along with several intermediate levels. Each level could be considered as a formal programming language. The specified levels are:

- The product model abstraction level
- The assembly part sequence abstraction level
- The assembly operation sequence abstraction level, or task specification level
- The robot and sensory generic language
- The target system dependent language, and
- The executable code

Figure 4. Mapping of sensor usability









SUBOPERATION	CONTROLLING	MONITORING	PROGRAMMING
PART IN THE MAGAZINE 			
SEARCHING FOR THE PART 	FINDING PART POSITION		PROGRAMMING OF PICK-UP POSITION
GRIPPING OF THE PART 		MONITORING OF GRIPPER FUNCTION AND GRIPPING	PROGRAMMING OF PICK-UP POSITION AND DELAY TIME
TRANSFER OF THE PART 		DETECTING COLLISION. DETECTING LOST PART	
SEARCHING FOR START-POSITION OF INSERTION 	FINDING START POSITION	DETECTING COLLISION	PROGRAMMING OF START-POSITION
INSERTION 	CONTROL OF ROBOT MOVEMENT	MONITORING ASSEMBLY FORCE AND SIGNATURE	PROGRAMMING OF INSERTION PATH
JOINING 	CONTROLLING TOOL POSITION AND TOOL OPERATION	MONITORING JOINING FORCES AND FORCE SIGNATURE	PROGRAMMING OF TOOL POSITION
FUNCTIONAL TEST. CONTROL OF ASSEMBLY OPERATION. 	FINDING END POSITIONS	MONITORING MOVING PARTS	PROGRAMMING OF POSITIONS USED IN TESTING
POTENTIAL USE OF FORCE/TORQUE SENSING IN ROBOT ASSEMBLY.			

Figure 5. Vision- and force-sensing in co-operation

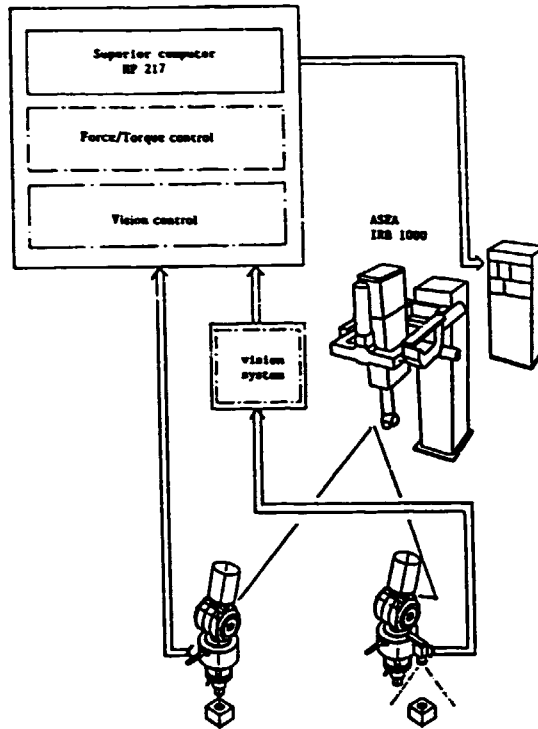


Figure 6. Hierarchical structure of assembly planning and programming

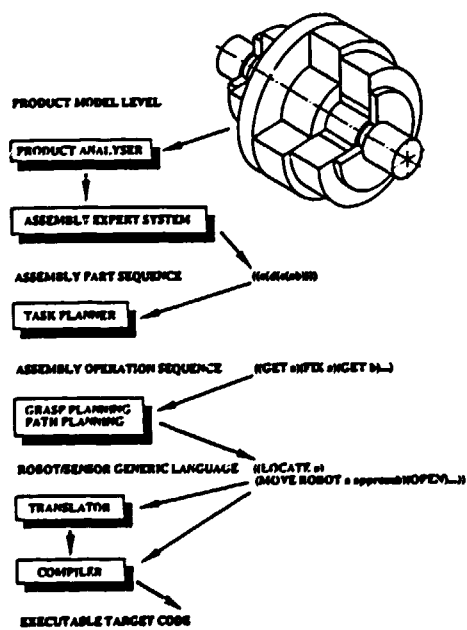


Figure 7. A product for assembly

1. LARGE_LOCKER_RING,
2. QUILL,
3. MEDIUM_GEAR,
4. LARGE_GEAR,
5. SMALL_GEAR,
6. SMALL_LOCKER_RING,
7. SHAFT.

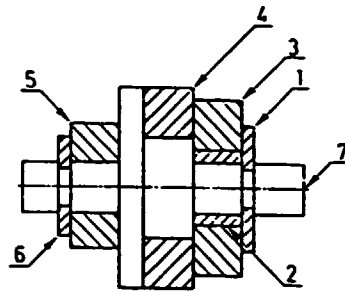
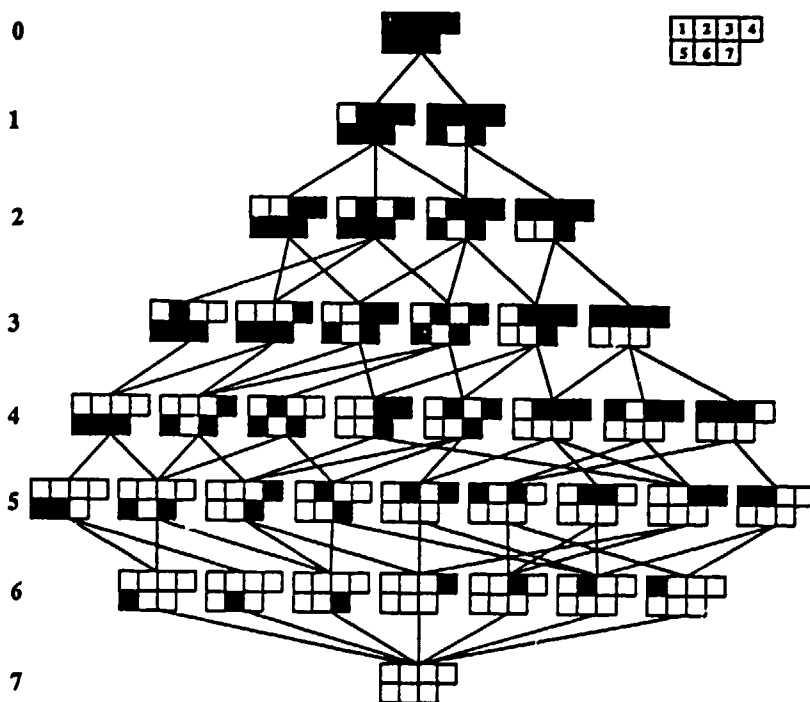


Figure 8. The assembly graph for the made-up product.
Parts in level six constitute a possible base part



Depending on the programming tasks and the programming experience, such a system would make it possible to enter the system at the best suited level of programming. All the different levels are shown in relation to each other in figure 6.

Furthermore, to accomplish automatic generation of executable programs for the target system, e.g. the computer-controlled assembly devices in the FAS, from the product model several software modules have to be developed and incorporated into the system as interfaces between each hierarchical level.

The purpose of each module is to synthesize the program code in the next, lower, level of assembly abstraction in the hierarchical system. When these modules are executed in successive order, the automatic planning and program generation will be carried out.

The necessary software modules are:

- The product model analyzer
- The assembly expert system
- The task planner
- The grasp planner
- The path planner
- The compiler

The system is independent of the assembly devices from the top down to the task planner level. Below this level the system will require a real world model of the physical assembly devices and the layout.

The product model analyser uses as input the geometric product model. It will automatically retrieve knowledge from the geometric product model, transform the knowledge to a symbolic representation of feature, attributes and structures of all individual components and the assembled product, generate a database and store this new product model. A graph

representing all geometric valid assembly sequences is also generated and stored by the product analyser. Following any ordered sequences of arcs in this graph from the terminals to the root corresponds to the accomplishment of the assembly. The graph is generated through disassembly. During the graph generation, the product analyser stores the disassembly motions to be used later in the reversed order in the fine motion planning of mating and insertion operations.

For a certain product (figure 7), 144 geometrically valid assembly sequences are generated (figure 8).

The problem now is how to select the best assembly sequence among all the options. This is the task for the assembly expert system. The knowledge represented in this system is non-geometric knowledge and it could be considered as the heuristics of assembly planning. The knowledge is compiled through "knowledge engineering" in the manufacturing industry, structured and suggested to be represented in a rule-based system provided with "if-then-production-rules."

Examples of rules that can be used in base part selection are:

- If part_i encloses the rest-of-parts, or if rest-of-parts concentrically enclose part_i, then part_i base part.
- If part_i has more physical contacts with the rest-of-parts than any other part_j has, then part_i base part.

Example of a rule that selects valid sequences is as follows:

- If base part has more than one assembly vector, and the difference in direction is more than 90° then complete one direction at a time, before indexing.

The finally selected path could be written as:

```
(SHAFT SMALL_GEAR SMALL_LOCKER_RING
  LARGE_GEAR QUILL MEDIUM_GEAR
  LARGE_LOCKER_RING)
```

As indicated above the sequences are internally suggested to be represented in a list with the base part as the first element.

The product model analyser and the assembly expert system has transformed the assembly task given as a product model to a description, not only as a geometrically valid assembly sequence but also as the best assembly part sequence according to the represented assembly rule (figure 9).

The task planner module will operate on a symbolic model of the assembly and the real world. A database with two main sections, the current assembly state and

the final assembly state, is used to store this model. The initial assembly state corresponds to the disassembled product and equals the first current state. The final assembly state corresponds to the completed assembly. The planner is guided by the part sequence.

The result from the task planner is a more detailed specification of the assembly task described as a sequence of assembly operations. This task specification is still an implicit specification in the sense that it only requests the system to perform an operation, not how or where to perform it. The sequence would appear as:

((GET shaft) (FIX shaft fixture) (GET small_gear)
(PLACE small_gear_shaft).....)

This assembly operation sequence is the corresponding expansion of the assembly part sequence. The program generated so far is still considered an implicit program specification. No explicit information is available on how each individual operation should be performed. Further program generation on lower levels will not be covered here, but an example will be given in the next section.

However, systems such as GRASP, CIM-station or RobCAD could be used for grasp and path planning, and robot programming languages like VAL or OIP for control code generation.

4. User-orientated system interfaces

As mentioned, an integrated manufacturing system will not show deterministic behaviour, but may suffer from various disturbances due to non-ideal components. This may have a serious effect on the availability of the system and thus on its productivity. Availability, however, is not only a function of the frequency in which disturbances occur, but also of the recovery or repair time. Short repair times will keep up availability. It is therefore necessary to have both an efficient system monitoring function and an efficient recovery system.

Both the monitoring and the recovery functions are highly operator-dependent. It is the operator who reads the signals from the monitor or directly from the system and decides on the proper action. He must

possess the required competence and even more important, he must be motivated to react. This has largely been neglected in the past, when deterministic systems have been developed with supposedly little or no skill required from the operators. In complex systems the result is usually a prolonged implementation time and poor availability.

Behavioural scientists are now focusing on effects of human impact on automated manufacturing systems. To gain positive effects there is a need for improved technical support for the operator. As in continuous process manufacturing he will need information on status and trends in system performance and not just an alarm bell. He will also need user-friendly tools to interact with the system, like rerouting production flow or reprogramming or repairing equipment. These tools will give him actual control and increase his confidence and motivation.

An example of such a tool is a graphic-supported robot programming system for assembly, developed as one out of three modules of a shop-floor decision support system, the other two being a Planning Simulation module and a Supervision module, respectively (3).

Graphic programming environments for industrial robots are very powerful tools for the programmer. The ability to manipulate, simulate and test robot cells reduces the errors and the implementation time. However, the majority of these tools, presently

available, are based on high-end computer technology and specially designed, complex graphics processing capabilities with an unfavourable cost factor. The system described here is a low-cost, easy-to-use, simplified, generic system for off-line programming tasks such as:

- Operator programming of industrial assembly cells
- Programming of single-robot systems
- Flexible programming for product variants
- Creating program skeletons to be adjusted and completed on-line
- Testing the logic of a proposed robot program.

The system is based on a standard PC and widespread CAD-system (AutoCAD version 10 by AutoDesk).

The robot programming is aided by graphical programming support, using qualitative icon-graphics, symbolic geometrical forms, compound coding etc. The user is provided with icons/objects representing the robot manipulator and the task to be performed (figure 10).

START · MOVE · GET · PUT · STOP

- The robot envelope is designed and calibrated by uploading location co-ordinates from the robot to the CAD-system.
- The actual programming is done by placing the task "objects" (as shown in figure 10) in the working area of the robot.
- The integrated Programming Support System (PSS) will present path tracing and intermediate steps to allow the programmer to edit the program graphically.
- The PSS will then extract relevant data from the CAD Database and post-process it to fill the requirements of the robot-specific programming language syntax.
- The complete robot program is then downloaded to the robot-specific off-line programming system for compilation or interpretation.
- Robot start and on-line confirmation/adjustment of the new robot program is performed.
- Uploading and decompilation of the adjusted program to the program library can then be done.

Referring to the previous section of this paper it becomes evident that AI planning and graphics-based programming can complement each other, forming a

powerful tool for the operator responsible for assembling of a certain product. Work is underway in this direction and a demonstration system is reported (4).

5. Conclusions

Three different techniques important for achieving integration have been exemplified: sensor control, AI planning and, programming and user interface. They are not independent of each other; on the contrary, they are very closely related and each one is a prerequisite for the other. AI planning and programming will fully automate the manufacturing data processing down to the the control code for the machines. However, in order to execute the code it must be updated and adjusted for tolerances and other variations in material and equipment. This is taken care of by the sensor feedback (figure 11).

The result is automation of all necessary routine work, leaving the operator free to decide and interact in order to achieve the most efficient production performance. In addition it will provide the operator with powerful tools in the form of status information, suggested actions and easy-to-operate communication facilities with the manufacturing system.

These techniques are still in their infancy and the need for further development is evident. In order for sensors to be effective in a complex environment, priority rules or other means are necessary for sorting out information from multiple sensors. Here again AI will play a role. Planning and programming, in particular in assembly, is a very unstructured problem. Up to now assembly sequences and sub-operations are governed by experience and informal rules. To run AI planning, formal rules must be established based on a structured description of the assembly work. This is a completely new field of research. Finally, the importance of human interaction with the system for high availability and optimal performance has only recently been recognized. Analysing manufacturing systems with respect to effects of human interaction is a far from regular procedure and tools for this analysis are not well developed.

It is quite evident that manufacturing processes must be redefined and reorganized in order to find the right balance between routine work that can be fully automated and high-level decision-based interaction in programmed functions with man in control. Only in systems where this balance is in operation with full technical support will integrated manufacturing be a reality and CIM become more than just electronic data transfer.

Figure 9. The selected path through the graph

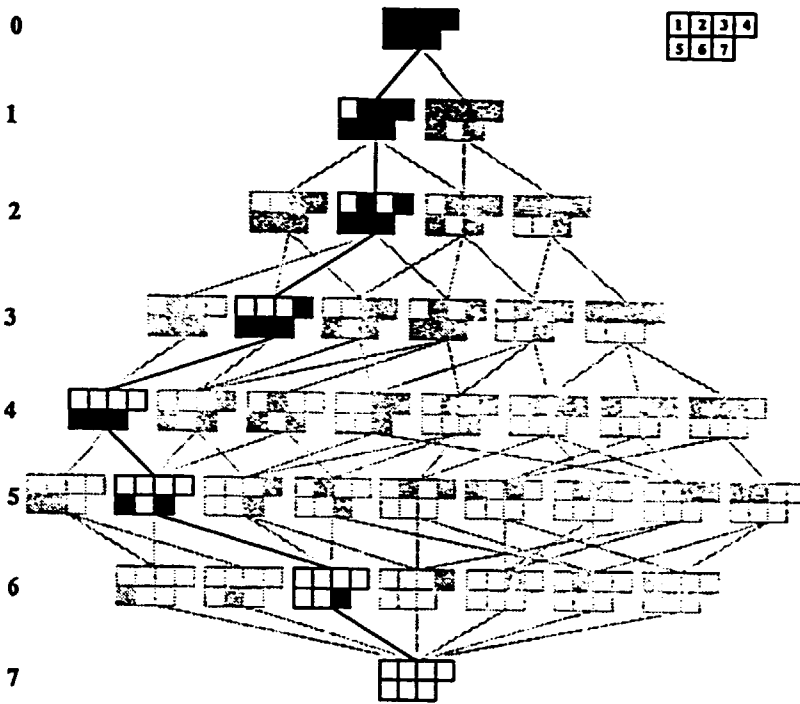


Figure 10. Graphic representation in robot cell programming.

Tasks represented are from left to right:

- START • MOVE • GET • PUT • STOP

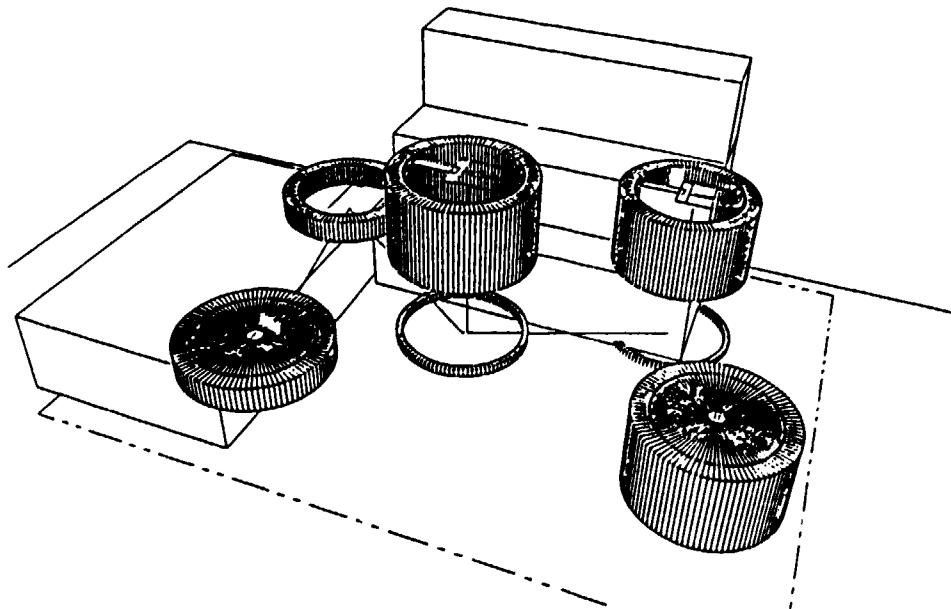
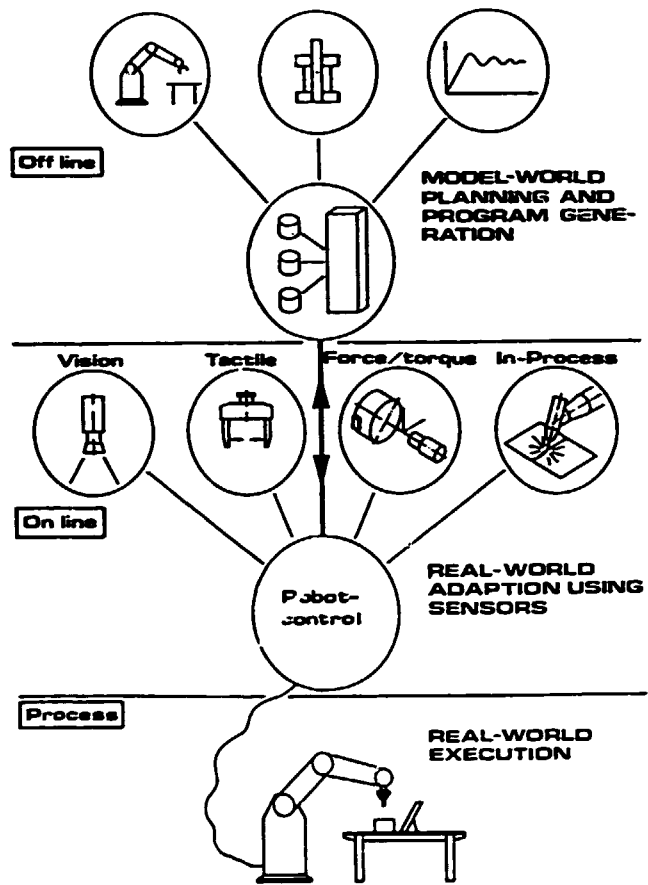


Figure 11. Planning, programming and sensor control for automatic execution of assembly operations.



Notes

1. *Wennström, L.; Mårtensson, N.*, "Force Torque Sensing for Monitoring and Programming of Assembly Operations". *Annals of the CIRP*, Vol 37 1/1988.
2. *Almgren, R.*, "On Knowledge Based Planning and Programming Systems for Flexible Automatic Assembly". LiU-Tek-Lic-1989:16. Linköping University, Sweden.
3. *Nordlöf, U.*, "AutoCAD integrated with Off-line Programming for Industrial Robots". LiTH IKP-Ex-632, 1987 (in Swedish), Linköping University, Sweden.
4. *Stahre, J.; Almgren, R.; Mårtensson, N.*, "Robot Task Planning Using AutoCAD". Proc. 20th International Symposium on Industrial Robots, Japan Ind. Rob. Ass., Tokyo 1989.

IMPLEMENTATION OF CIM IN AN ELECTRONICS FACTORY STEP-BY-STEP

by F. TOMANCOK, Siemens AG, Vienna, Austria

Introduction

In addition to considerations related to quality and production costs, flexibility and just-in-time production techniques are rapidly gaining significance. Flexibility is not achieved through high inventory but through short reaction times in development, procurement, production, and sales. Under conflicting market and economic conditions it is not enough to optimize single functions. Instead what is required is an assessment of all the interrelated overlapping issues.

CIM offers a solution to these problems.

In order to cater for the new market demand, Siemens has developed a CIM-concept and has been implementing it step by step since 1988.

This paper introduces this CIM-concept, as well as two realized projects – the PPC system and the automated storage – as an illustration of the CIM-concept.

The programme has five parts:

1. Presentation of the SIEMENS factory "Gerätewerk Wien"
2. Explanation of the CIM-concept
3. Description of the realized CIM-project "production planning and control" (PPC)
4. Illustration of the automated storage system
5. Summary.

1. The SIEMENS factory in Vienna (Gerätewerk Wien)

The "Gerätewerk Wien," an electronics factory of Siemens AG Austria, was established in 1972 and started its production with mainly electromechanical products.

Over the past years, the whole production program has been changed to exclusive electronics products with two main fields:

- Drives for DC- and AC-motors with a production volume of about 20,000 pieces per year; and
- Power supplies especially for automation devices and systems with a production volume from about 200,000 pieces per year.

The factory employs about 500 persons of whom 80 work in technology and development, 70 in administrative and commercial departments and 350 in production and quality assurance. The yearly turnover is about US\$77 million, 98 per cent of which comes from exports. In the past five years yearly growth rate has reached about 20 per cent.

2. The CIM – concept

The CIM-concept is oriented on the CIM model of SIEMENS factories described in this paper (Figure 1). The aim was to cover all PPC, CAE and CAM functions with data processing systems integrating already existing company-wide systems.

Figure 2 presents a simplified system flow-chart of our CIM-concept. In the field of computer-aided engineering a system for storage of basic technical data was introduced. The following functions are based on this system: circuit diagram generation (CAD), design of printed circuits, mechanical construction (CAD), components list- and production plan generation (SIAPS). The data of the four CAD systems are connected with production and quality process-level via the NC-program generator (STAB). The basic production data are stored in PROSIS P.

In the field of PPC, existing slow data processing systems were replaced with new dialogue systems and all paper interfaces were cancelled. All PPC systems were linked with CAE and CAM systems.

The PPC modules, production control and disposition, are described in detail below.

Figure 1.

CIM - Functional Diagram for SIEMENS UBE - Factories

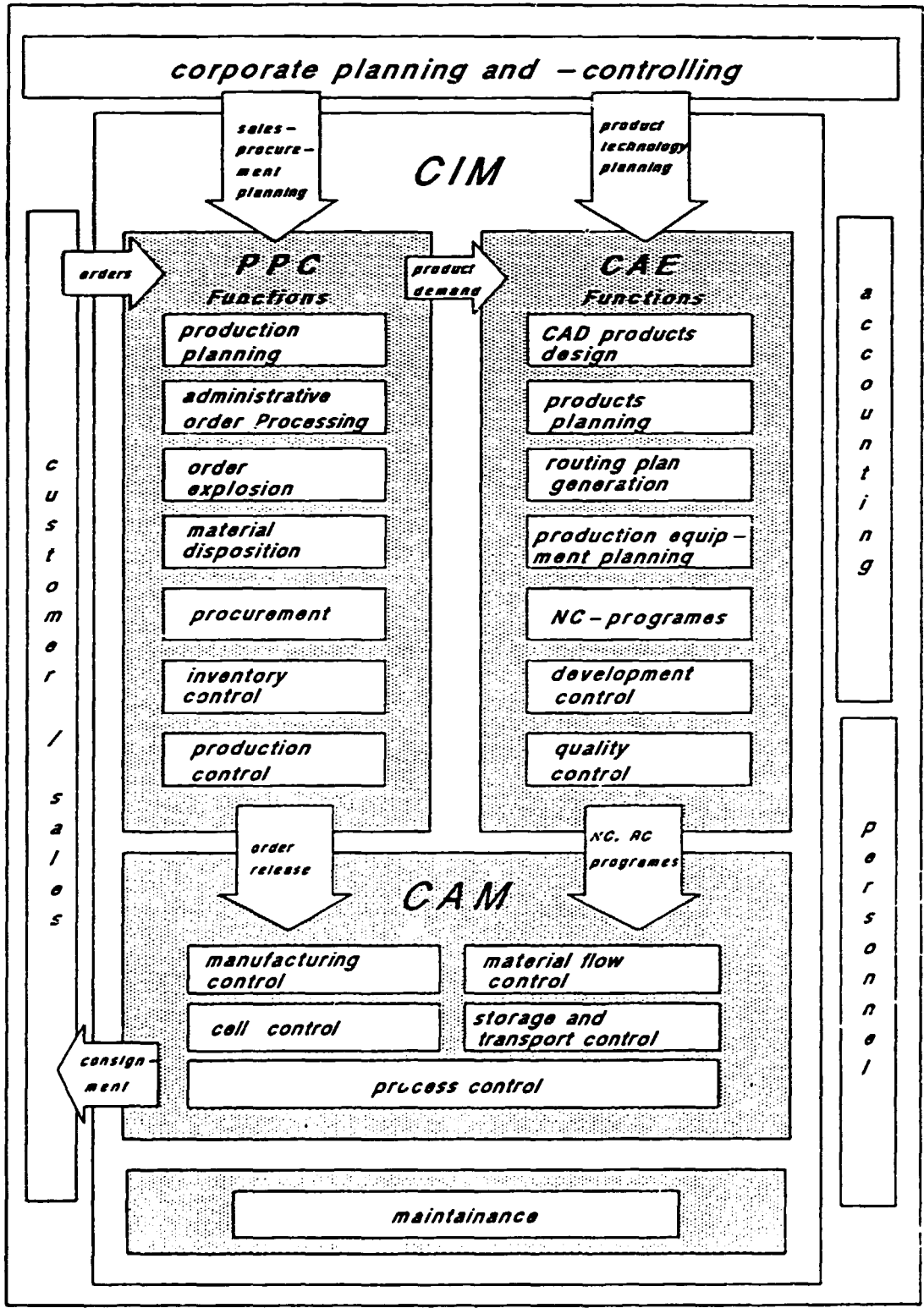
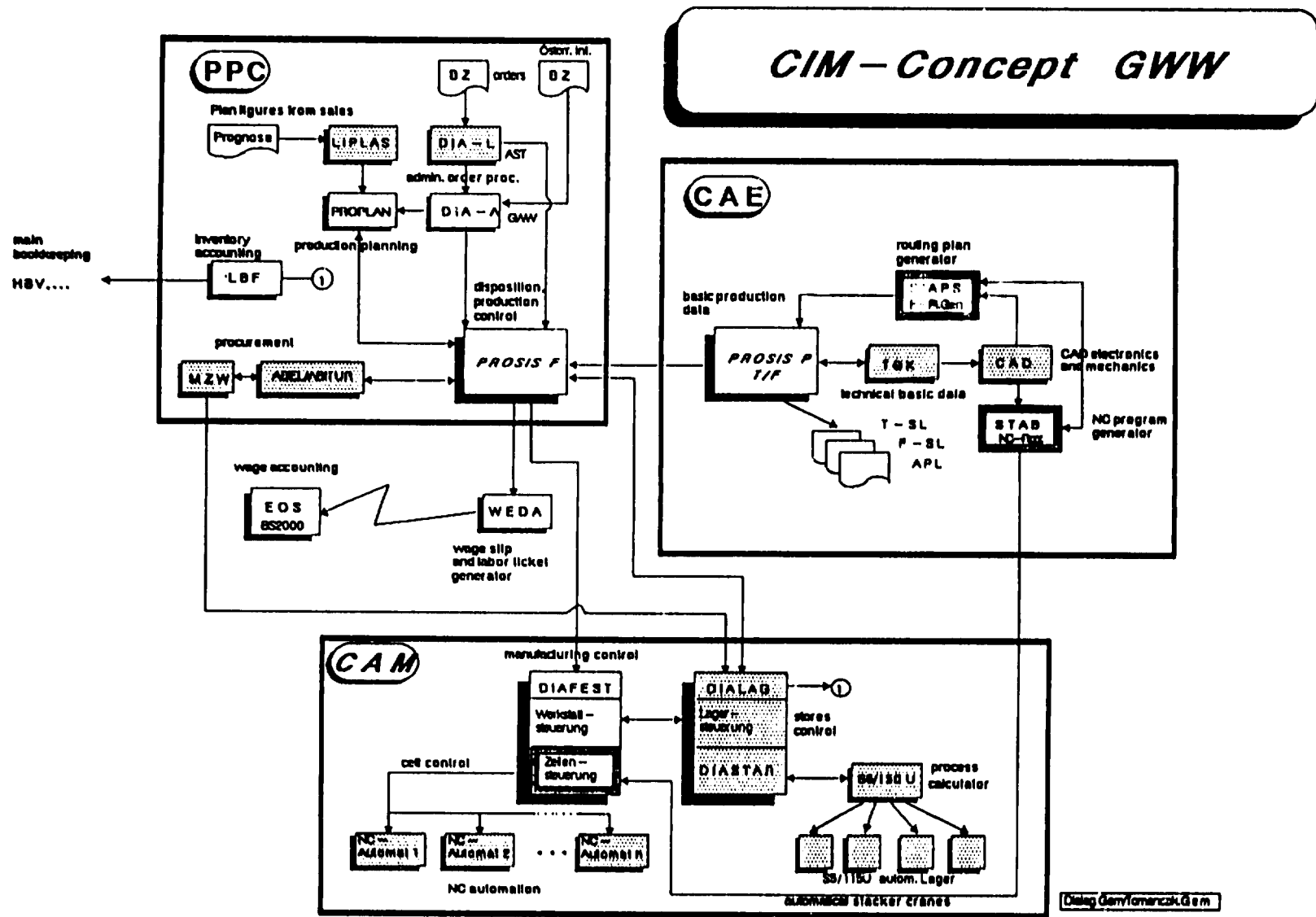


Figure 2.



The computer-aided manufacturing complex is divided into three parts: the controlling level, the cell level and the process level, for example the NC-automation and storage stacker cranes. The three levels are technically linked with each other and with the PPC and CAF systems. In the field of material flow control, with the automatic storage, free data flow from PPC to the process level of the stacker cranes was realized. Production and quality assurance will be integrated into the CIM system with similar networks.

3. The PPC-system

As an example of a successful CIM project, I will illustrate our PPC system in terms of its disposition and production control.

The production planning system is fed on the one hand by plan figures from sales and on the other hand by the actual business data from the administrative order processing. These data are linked with current production orders, thus providing a production program. The production program is subdivided down to components level. Basic data are supplied from the CAE system PROSIS P. These data provide the basis for automatic material and parts disposition.

The system checks stock availability and open purchase orders and generates new orders in case of undercoverage. Disposition rules such as minimum stock level or fixed batch size are taken into account.

Incoming goods data are fed into the disposition module of PROSIS F through the automatic storage control.

An additional PC-software has been installed which offers very comfortable inventory analyses. Figure 3 presents a storage input output analysis: the lower diagram shows the accumulated output, the upper one the accumulated input. The difference between the two diagrams indicates the stock-level development.

In the event of differences between the actual and the rated stock level, the stock manager is given a signal to adapt his orders. The system calculates trends in demand as well as the level of safety stock dependent on the desired service level.

As for the production control system, production orders are transferred from administrative order processing (DIA-A) to the production control system PROSIS F. Basic production data are transferred from the CAF-system PROSIS P. The production

controller checks the availability of material and capacity and releases orders for production. After that, the order is transferred to the manufacturing control system. The necessary material data are transferred to the storage control system DIAIAG. Destocking is initiated by the production. Each production step is reported back to the production control system.

The use of the new production control system made it possible to have the manufacturing process time and consequently the floor stock.

4. Automated storage system

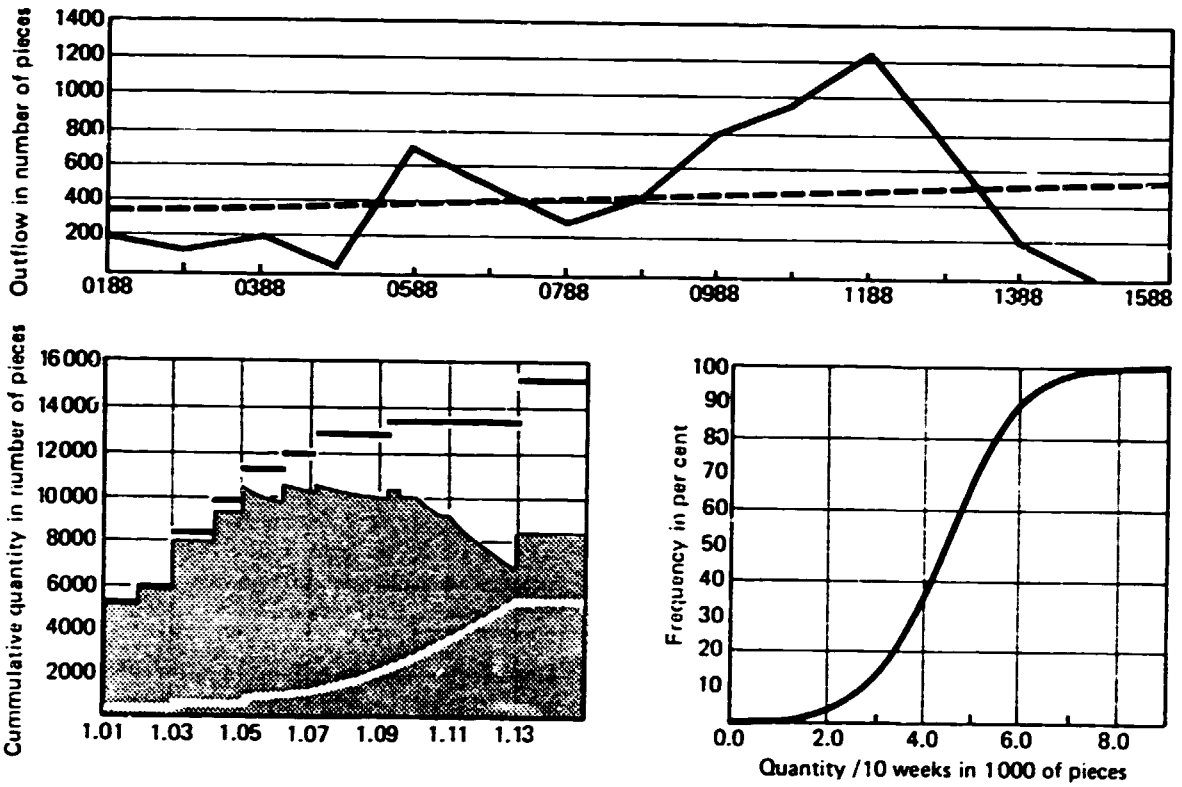
The automated storage system is organized as an automatic surface storage. It offers room for 12,000 storing places in six rows of shelves on an overall area of 400m². Incoming goods are repacked into standardized containers in the receiving department. Depending on the size of these containers, three or six of them are put on standardized trays, which are marked by storing place addresses and which have a fixed place in the storage system. The above-mentioned trays are automatically transported to the takeover stations of the stacker cranes. These cranes transport them to their respective shelves. The transport system is controlled by a SIMATIC process calculator which is linked to the main stock control calculator.

The internal ordering of the trays for destocking is activated by four stations via screen and keyboard. Destocking is initiated by the production control system. After order release, the necessary order material is reserved for destocking. The commissioning personnel receives the material positions of the most important orders, one by one. Destocked material is marked with a label showing quantity, material number, order number and manufacturing department. Commissioned orders are at the disposal of the manufacturing department.

In front of the storage there is a computerized incoming goods department. Data of incoming goods are processed and handled automatically from quality control to storage.

The stock manager is able to keep track of all material from the moment of reception and, if necessary, to state priorities for testing and storage. Material which is needed immediately by the manufacturing department is delivered automatically instead of being stored.

Figure 3.



Moreover, the storage control software offers:

- Retention of the first-in first-out principle
- Continuous availability of stock-level information
- Automatic container inventory at zero level
- Possibility of establishing priority of orders and single positions
- Stock place administration with registration of suppliers
- Automatic delivery in case of container differences.

About 1000 positions are stocked and destocked every day. The stock processing time amounts on average to one working day. This is about a quarter of the time necessary prior to data processing.

The project was realized according to the following timetable:

End of planning	November 1987
Steel construction	December 1987
Electrical installation of storage technology	Jan. 1988 – Feb. 1988
Test phase including software	Feb. 1988 – May 1988
Moving in	May 1988 – June 1988
Productive use	since July 1988

Profitability of this investment is based upon better storage and commissioning quality, automatically controlled processes, shorter processing time and therefore lower capital tie-up effective use of space, high transparency of stock and exact inventory accounting.

At a cost of US\$2 million for hardware and software, the profitability amounts to 20 per cent.

5. Summary

The data processing systems presented above were developed in co-operation with the Siemens software house in Vienna, the so-called "Program and System Engineering." At the moment, about 60 per cent of the CIM-concept is in productive use. Implementation of the remaining 40 per cent will be realized in two or three years.

With a total software cost of about US\$1.5 million, a profitability rate of about 30 per cent is expected.

The use of the new system made possible a turnover increase of 50 per cent in the past two years. The increase of personnel expenditure for administrative work, however, was negligible.

This obvious success fully justifies the efforts made to implement CIM.

A CAD-ORIENTED AND A CAM-ORIENTED PILOT PLANT IN HUNGARY

by G. L. KOVACS, Computer and Automation Research Institute, Hungarian Academy of Sciences, Budapest, Hungary

1. INTRODUCTION

The automation of discrete part production was supported mostly by means of centralized DNC (Direct Numerical Control) computers in the beginning of the 1970s. This kind of hierarchical control structure was used in three different integrated manufacturing systems in Hungary. Our institute had a decisive role in the design and implementation of these systems (1). With the appearance of up-to-date CNC controllers, these systems were developed into cell-organized integrated manufacturing systems. However, they kept their original architecture (2).

Later on, from the second part of the 1970s, the distributed control systems became more and more important in industrial applications (4). Integrated manufacturing systems were designed to help automation at the shop-floor level (Figure 1).

As the following generations of controllers, the standardized PROWAY (MAP) and MAP/TOP systems appeared. These were already designed and implemented with uniform interfaces.

2. DISTRIBUTED CONTROL SYSTEM ARCHITECTURES

The local area network (LAN) based (e.g. MAP) control systems may have different structures (5):

- Figure 2 shows a version, where the cell controllers are connected with each other on the same level. One of the cell controllers may have a "host" task with increased responsibility, but it is not necessary.
- Figure 3 presents a network where not only the hierarchically equally ranked elements are connected to the same level, but cell controllers, CNCs, PLCs, RCs and even a "host" computer may be present. In the case of larger systems the net consists of different segments, which are connected by means of the so-called bridges.
- Figure 4 shows a network, where the shop-floor MAP networks are connected to the factory-level MAP backbone by means of gateways.

This kind of system architecture makes it possible to connect different types of networks, such as ETHERNET, token-ring, token-bus, WAN, etc.

3. CIM SYSTEMS SERVING RESEARCH AND DEVELOPMENT AND EDUCATION

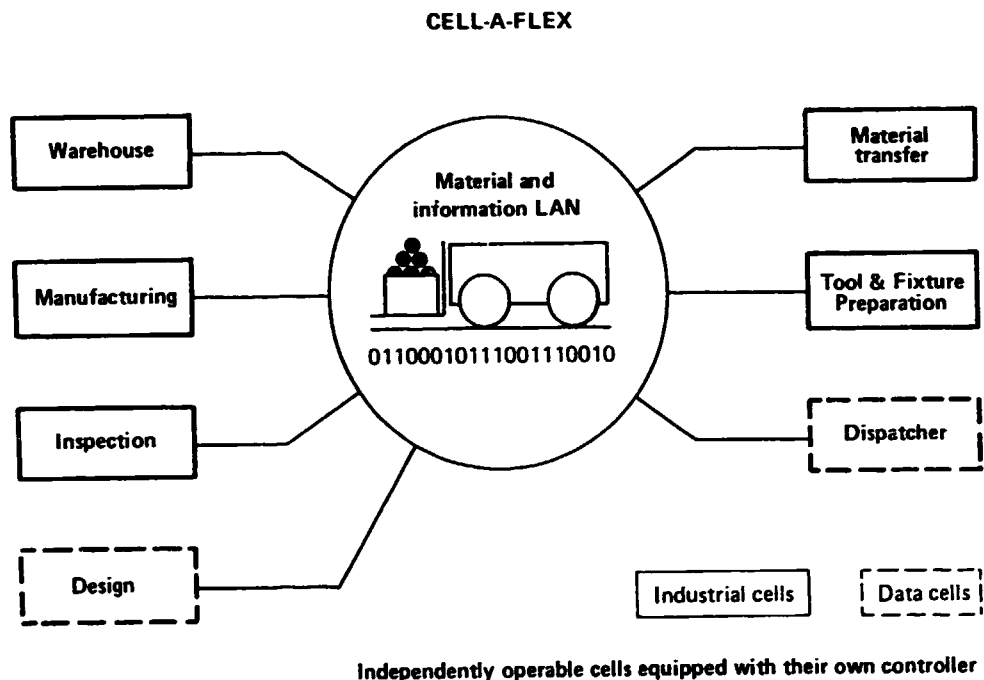
The implementation of a complex CIM system started in 1987 in the Computer and Automation Institute, CAI (8). This system consists of different computers, connected by different networks and it has some mechanical engineering tools (a small workshop) as well. The implementation is not yet completed, but some parts are working in experimental regime. The primary goal of the system is research, development and testing using the means and programs of the computer aided design in the field of mechanical engineering. Involvement of industrial people is a very important target, too.

At the same time a similar development started at the Technical University of Budapest (TUB) (9). Because of the nature and size of the TUB, the implemented system will consist of more different networks, computers and mechanical engineering means. An important subsystem of the system will be a pilot plant consisting of different cells connected by a MAP-like network. This paper deals only with this subsystem which will be a test pad of the programs and means of computer-aided design, manufacture, diagnostics and quality control.

Both the CAI and TUB system development and implementation are partially supported by government agencies (Ministry of Industry), as such central supports are essential for the success of such sophisticated, wide-range projects.

As both systems have several similar elements, and a lot of people of the CAI and of the TUB staff will have access to the facilities of both systems, the main characteristics of the two systems will be discussed together. For the sake of simplicity, the CAD-oriented CAI system will be called CAI system, and the CAM-oriented TUB system will be called TUB system throughout this paper.

Figure 1. Manufacturing system based on cells



3.1 The main objectives of the systems

The basic goals of both systems are the same:

- To improve the research-development-education possibilities to support the efficacy of work in both institutions.
- To support unification (standardization) on the Hungarian CAD/CAM scene. This should be done in accordance with international standards from the point of view of systems and system elements as well, using as much "home-made" (Hungarian) elements as possible.

3.2 System requirements

3.2.1 Common requirements:

- Access should be provided to all Hungarian and available foreign CAD/CAM programs. This means access to all precise, up-to-date documentation. Interfaces should be provided between the programs within the systems and to programs which are not yet integrated.
- The systems should always be ready to demonstrate all the new (and older) R&D results for internal and external experts.
- The systems should be used for graduate and post-graduate education.

3.2.2 CAI system requirements:

- A high-performance, high-speed network should connect appropriate 32-bit computers and peripheral equipment to run 25-30 programs simultaneously. 3-5 of these programs may be high priority interactive graphical ones, with high CPU demand. The system should serve altogether 50-60 users.
- As the system is planned mostly for CAD purposes, the CAM part and the production side (mechanical engineering elements) are restricted to a minimum which is enough to test and demonstrate the results of the computer-aided design programs.

3.2.3 TUB system requirements:

- The complete system should provide access to the resources of the central, 32-bit computers of the Technical University of Budapest for all the computers of several departments, which are situated in 6-8 buildings within a 600-meter diameter circle. These central computers should be reached simultaneously by 50-70 terminals. The personal computers can be used as terminals, too. At the same time, the personal computers close to each other should work together in independent local networks.
- The target of our recent study is only one part of this system, which will be a flexible manufacturing system built up from different cells, which are connected by a MAP-like network with each other and to a 32-bit higher-level computer.

This CIM subsystem should provide the possibility to investigate the production processes, including turning, milling, welding, etc. and to investigate machine-tools, CNC and cell controllers. The running and testing of the available CAD CAM programs should be provided, too.

3.3 Proposed R&D activities on the CIM systems

3.3.1 CAI system:

The results and experiences in the Computer and Automation Institute of the past ten years in the CAD/CAM field are the basis of the work which will be done in the following years.

- The development of mechanical engineering design and manufacturing systems, based on surface and volumetric modeling. Research and problem-solving of product modeling.
- Research of different level MAP networks and in the field of network compatibility.
- The research and development of control systems of flexible, integrated manufacturing cells and systems, and of robot and machine-tool controllers.
- R&D of automatic measurement and supervision of machine-tools, and machined parts during manufacturing, using computer-aided diagnostics.
- Application of the methods and means of artificial intelligence, as e.g. knowledge-based and expert systems to the above listed R&D fields.

Figure 2 .Cell controllers on a network

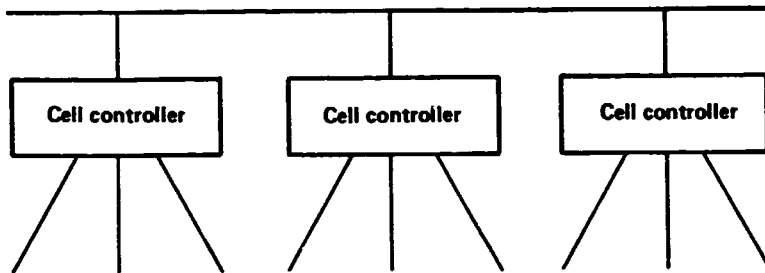


Figure 3. Hierarchically different elements on a network

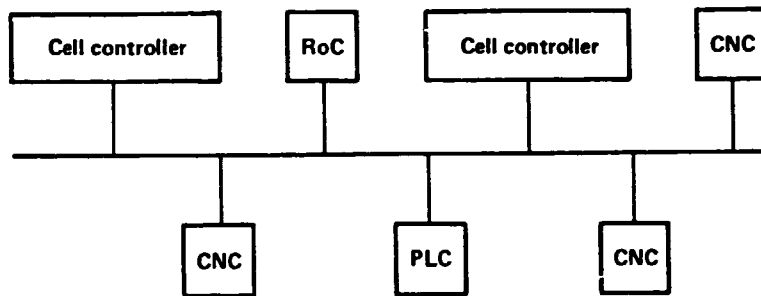
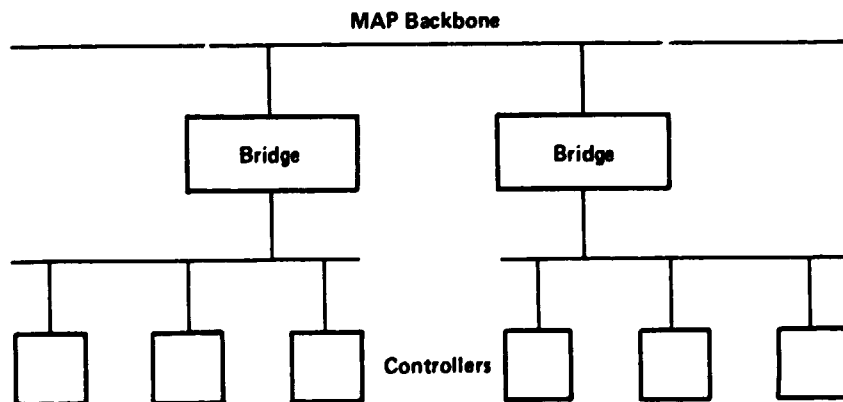


Figure 4. Factory-level and shop-floor networks



3.3.2 TUB system

This system will be used mostly by the staff of the Department of Mechanical Engineering, and by the members of the other departments of the university, and by research and development people of connected institutions. The R&D activities on the system will be based on the outstanding technical and scientific results of the Department in the past years, including:

- Research of control systems of manufacturing processes, and of integration of different production systems.
- Cell- and system-level implementation of MAP protocols.
- Coupling of manufacturing system controls with production planning and other preparation packages.
- Research and development of different fields of attendance-poor manufacturing, such as:
 - material handling;
 - data- and material-flow, using intelligent cell controllers;
 - fixtures, pallettes;
 - technological design;
 - production planning systems;
 - co-ordinate measurement technique;
 - testing of workpieces and tools during cutting processes;
 - reliability tests and state supervision.

Some of the above tasks should be solved already to provide an error-free operation of the system.

3.4 System architectures

To reach the above goals and to solve the above-mentioned tasks the systems will be structured as shown in Figures 5 and 6. The main components of the systems are the following:

3.4.1 CAI system (Figure 5):

- 32-bit computers connected by means of an ETHERNET backbone network, mostly for CAD purposes.

- MAP network to make connections with the process-control and manufacturing system-control VME systems.
- Special, goal-oriented subsystems, which can be connected either to the computers of the backbone or to the MAP network.
- Mechanical engineering elements connected to the MAP network (machining cell, measurement cell).

3.4.2 TUB system:

- The complete system consists of 32-bit megamini and 16-bit minicomputers connected to an ETHERNET network. The local networks which contain IBM-like PCs are connected to the ETHERNET.
- The 32-bit computers of the CAM system are directly connected to the ETHERNET network.
- The FlexCell cell-controllers (IBM PC/ATs) are connected to a MAP-like network, which is connected to the ETHERNET via a 32-bit minicomputer.
- According to the recent plans, the system contains the following cells, from which the manufacturing cell already operates.
 - Manufacturing cell (CNC lathe & CNC machining centre, served by robot and by PLC)
 - Material handling and storing cell (pallettes, AGV, buffers, tool stores with intelligent supervision, etc.)
 - Assembly cell (robot, vision-module, force-torque sensor, etc.)
 - Measurement cell (CNC co-ordinate measurement machine, manipulator, table, etc.)
 - Material preparation cell (welding, manipulators, AGV, etc.)
 - There are plans to implement 1-2 further cells.

The material flow between the main cells is represented in Figure 7. The material flow is realized by means of robots, manipulators, and AGV.

Information flow is solved by a MAP-like network between the cells and from the cells to the 32-bit computer which is connected to the ETHERNET.

Figure 5. CAD-oriented CAI CIM-system

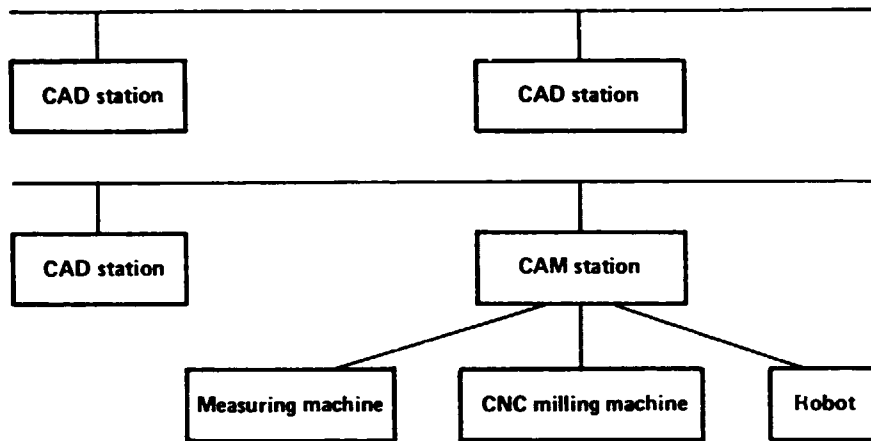


Figure 6. CAM subsystem of the TUB CIM system

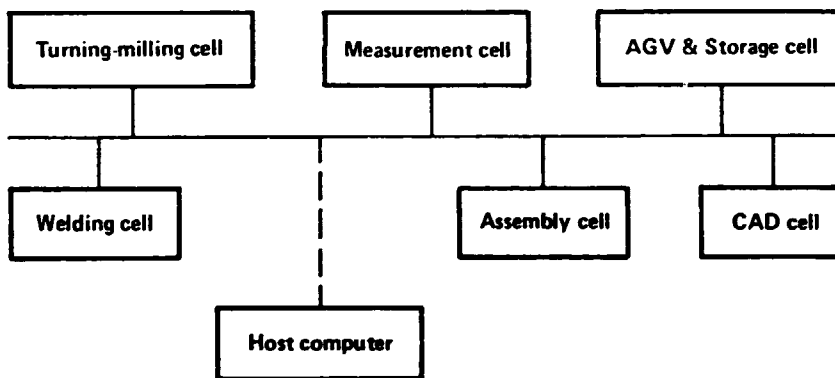
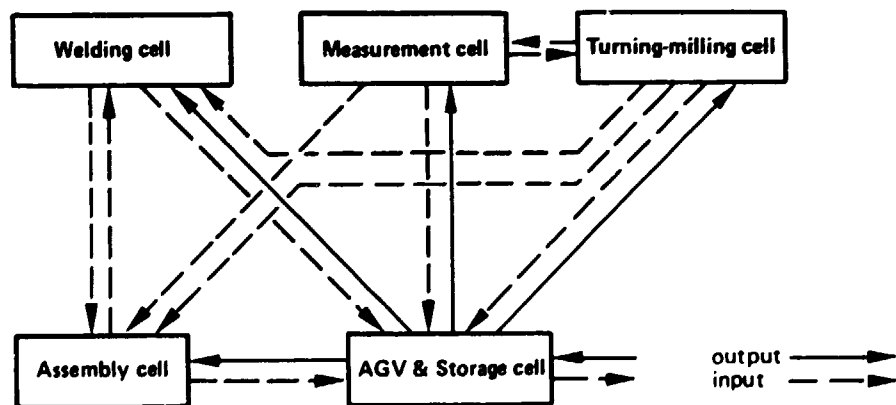


Figure 7. Material flow in the TUB-system



4. ADVANTAGES OF CAD/CAM NETWORKS AND PROTOCOLS

Unification and standardization of information and control systems can be based on local area networks (LAN). As long as there is a homogeneous computer park, a DECnet or SNA network can be advantageous. However, most industrial manufacturers use different kinds of computers in the same plant or factory. To connect the different computers, a standard network must be used. The MAP/TOP standardized protocols now seem to be the optimal solution.

The MAP project started in 1983 with more or less utopian goals. The subsequent years resulted in great progress, and finally in 1988 the MAP/TOP 3.0 version products appeared on the market with a guarantee of staying unchanged at least for six years.

There are a lot of arguments against the MAP network protocol standards because of high prices, too high sophistication and the fact that there are only a few working references. In 1983 wide application was not expected earlier than 1988-89, as at least five years were necessary for the 50 leading enterprises to run co-ordinated R&D and to get useful, up-to-date results, which can become international standards for at least 6 years. Until now, more than 500 firms have expressed their willingness to accept MAP/TOP standards world-wide (7).

The American IBM, GM, John Deere, Eastman Kodak and others, and the European BMW, Volvo, British Aerospace, etc. started to implement MAP networks in a production environment. Together with the increase of industrial applications more and more dealers are suggesting MAP elements, cards, systems and services, that necessarily will lead to a fast price drop soon. According to certain forecasts, one MAP node cost more or less than US\$150 already in 1989-1990.

These are the reasons why we are supporting MAP/TOP networks even if they are hardly available today. If there is a lack of MAP interfaces, ETHERNET elements can be used temporarily as

substitutes. As the physical medium of MAP and ETHERNET are the same the application of MAP will not need new cabling. The ETHERNET interfaces can be changed to MAP ones step by step, and in the meantime the two types of systems will be able to work together.

5. CONCLUSION

The world-wide proliferation of highly automated manufacturing systems can be imagined only if the system modules are standardized (see ISO, OSI, MAP, TOP, VME, EIA, DIN, GOST, etc.). On the other hand, an up-to-date, possibly computer-aided design implementation methodology, such as SATT-DOC (3) should be applied. The working manufacturing systems have proven that big systems are getting more and more complex by adding new elements and by changing old elements and functions according to demands, which would not be possible without having standard subsystems and without a good design with a certain "look-ahead."

Active co-operation between different countries in R&D and in implementing systems is impossible without respecting all international standards and prescriptions. The two CIM pilot plants, recently implemented in Hungary, are serving the above goals by giving companies a chance to use up-to-date software-hardware means.

The internationally accepted MAP/TOP standards are planned for application. However if certain elements are not yet available (as MAP 3.0 interfaces today), other standard elements (such as ETHERNET) would be used temporarily.

This way the systems can work without delay, and as soon as the circumstances change positively the appropriate elements can be substituted.

Information exchange should be organized within all countries and between countries concerning CIM systems and standards, thus all associations which plan to promote this goal should be supported. First of all, the ISO-OSI world standards such as MAP/TOP should be applied.

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SOFTWARE STRATEGIES FOR CIM

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1. Introduction

Software is a crucial factor for the development of computer-integrated manufacturing (CIM) (ECE, 1987). Knowledge stored in the form of software is used in the direct control of production systems, ensuring the automation of both material and intellectual production processes in CIM systems. The efficacy of these systems is largely determined by their intelligent component "software." And their efficiency is increasingly influenced by software costs during the whole software life-cycle. Social implications for the working people arise in the production process due to the interaction between "machine intelligence" stored in software and human intelligence and knowledge.

The development of efficient software confronts suppliers and users of CIM systems with strategic problems widely known as the software crisis. Their alleviation requires the elaboration and implementation of long-term software innovation strategies at both micro- and macro-level (Weber and Belitz, 1989).

An innovation strategy for the macro-level must increasingly become a necessary and co-ordinated guideline for the strategies of different participants in the innovation process on the micro-level (software engineers, suppliers and users) and not only an unconscious result of individual strategies. The control of the manifold relationships between the levels in the strategic management of innovation processes is becoming more complicated due to the synergy of high technologies (software engineering and CIM), and the resulting profound changes in the industrial structure. At present it is crystallizing as one of the general problems in innovation research. A research project called SOFTCIM (*software engineering for CIM systems*) has been initiated at the Institute for Theory, History and Organization of Science to tackle this problem.

This paper summarizes some of the results obtained up to now, based on the authors' participation in the elaboration of a software strategy for the German

Democratic Republic. The paper focuses on strategically relevant trends in international specialization and co-operation between software suppliers and suppliers/users of CIM systems, as well as on conclusions for strategy building at the national level.

The second part describes the aims of the SOFTCIM project and the framework for strategy building. All the other parts of the paper are devoted to analysing the strategic integration of software production, software research and CIM from an international point of view. Strategically relevant characteristics of software innovations for CIM serve as starting points. Then trends are characterized in the specialization and co-operation between the software industry, CIM suppliers and users, as well as forms of social co-ordination of strategic software research. The last section summarizes the German Democratic Republic's experience in the strategic management of software production, draws conclusions from international trends for strategy building at the macro-level and outlines future research.

2. A framework for strategy building in software engineering for CIM: The SOFTCIM research project.

The aim of the SOFTCIM research project is to elaborate a concept, a methodology and tools for supporting central state management and planning authorities, as well as economic units in strategy building in the field of CIM software. We are proceeding from the thesis that the strategic contradiction between demand and supply of CIM software can only be solved in qualitative and quantitative respects by *socially organized development* and widespread introduction of new software products and software innovations. The innovators' activities and the social efficiency of innovation processes are largely influenced by:

1. Knowledge about innovations and the course of innovation processes in a social environment, as well as by the innovators' capability to build and implement innovation strategies;

2. The formation of social conditions and mechanisms, which determine the innovators' aims, demand and the availability of natural and social resources.

In the past, innovation research focused mainly on the analysis and forecasting of trends in separate scientific and technological disciplines or innovation fields (e.g. microelectronics, flexible automation, computer technology, software technology) and the elaboration of strategic alternatives under stable social conditions. The development and synergy of these high technologies in the emerging new organizational mode of production that we call flexible production (Haustein, '989) make high and new demands on the socio-economic management of innovation processes, thus initiating a new stage in innovation research.

Today, the creation of a flexible and economically efficient system for managing and stimulating co-operation between all participants in technological change is the most challenging function of an innovation strategy. Therefore modern innovation research aims at:

- Identifying alternative directions for innovations, including their technological and social dimensions, and
- Supporting the innovators' actions by clarifying goals (strategy building at the micro-level) and their social co-ordination (formation of adequate socio-economic mechanisms at the macro-level).

Our framework for building software strategies (Weber and Belitz, 1989b) comprises two inter-related tasks – the socio-economic evaluation and the determination of guidelines for action – to be solved at two levels. At the micro-level, software innovations are being developed, implemented and used in research institutions and economic units ("innovators' level"). The social control of innovation processes is exercised at the macro-level by various co-ordinators (governmental and non-governmental, national and international organizations, associations, administration, legislation, banks, trade unions, interest groups in industry, research councils...). Individual and team working processes at the micro-level are being studied by disciplines such as software ergonomics, software psychology, software metrics and project management, thus providing the basis for strategy building. The two levels are integrated by the software infrastructure (Boehm and Standish, 1983), a system of information channels between the innovators and the co-ordinators.

In order to support strategy building, our research work within the SOFTCIM framework has been concentrated on the following subjects:

1. Micro-level:

- State of the art in the socio-economic evaluation of software innovations by CIM users;
- Structure of a simulation model (Weber and Belitz, 1989b).

2. Macro-level:

- Development of the software industry (including its infrastructure);
- Software innovation strategies that are being accomplished world-wide and new control mechanisms for stimulating innovations (Weber and Belitz, 1989a).

3. Strategically relevant characteristics of software innovations for CIM.

For the past two decades, the software industry has evolved with its own technological foundation in the same way as software has become a separate component (relatively independent of hardware and users) of embedded information systems (IS), for example in CIM systems.

At the same time, owing to its interfaces with hardware (systems software) on the one hand and with the user problem (application software) on the other, software engineering has become a new element both in hardware production and in production processes of suppliers and users of embedded IS.

As a form of knowledge production, software engineering has specific features distinguishing it from traditional material production. Most of the trouble suppliers and users of CIM software systems have, can be explained by the following peculiarities:

1. Software development is a creative intellectual team work. In comparison with other engineering occupations, the productivity of software engineers varies even more. Rigid working methods and formal discipline (Taylorism, software bureaucracy) usually set up barriers to creativity.

The need for software engineers to keep up with software technologies and management is a protracted process of bringing to maturity the software engineering culture (Humphrey, 1988) that differs essentially from the culture of hardware producers.

2. From an economic point of view, software development is unique production. R&D expenditures dominate the production costs and can hardly be planned or forecast. The time factor in the development phase becomes even more important, as copying takes practically no time, and the first supplier has the chance to conquer a large market share.

3. CIM software systems are more complex than hardware systems and have a longer life-cycle. That is why great demands are made on their reliability, portability and maintainability. There is a close dependence of software quality on the software technology applied.

Rapid changes in software technology, long maturation periods of technologies and long life-cycles of CIM software contribute to the growing significance of strategic CIM concepts and standards for open systems within the framework of which further innovations are possible.

4. The quality and benefit of CIM software are judged according to specific user requirements. As CIM concepts themselves are still evolving, requirements engineering is a complicated process of knowledge acquisition and knowledge management that can hardly be supported by methods and tools. For this reason users have to participate in software engineering, combining and extending their knowledge about user problems with the knowledge about software development. This requires new hybrid qualification profiles and a new division of labour and co-operation between specialists and economic units.

Experience has shown that CIM user problems stimulate further progress of software technology. In addition, the social relevance of CIM leads to high pressure on the efficiency of software engineering.

4. Trends in specialization and in co-operation between the software industry, CIM suppliers and users.

CIM is not a single technology, but rather a global concept. CIM systems have to be tailored to individual companies. Therefore CIM strategies vary widely and a large part of CIM software is still being produced in-house by users.

However, today there are not only numerous vendors of CIM components (hardware, software, turnkey systems, production systems), but systems of integration software and services for CIM are also offered on the world market.

Owing to the growing importance of software and IS services, structural changes are taking place in industry and research, the knowledge of which is a corner-stone for strategy building by economic units and research institutions. Of special interest are:

- The development of the software industry and
- Specialization and co-operation between software producers, CIM producers and users.

In order to support strategy building in software engineering for CIM, we analysed the statistics of the world's 100 leading IS companies published annually in "Datamation." This analysis revealed that these companies had the highest growth rates of revenues in IS services and software. The market segment of IS services is closely related to software production. Experts estimate that 30 to 50 per cent of the IS service revenues come from software (e.g. custom programming, system integration consulting).

In 1987, software accounted for 8.2 per cent of all IS revenues (IS services, 7.6 per cent). The share of these two market segments in the leading firms' revenue has increased since 1984, showing that efficient software production is an important factor for success.

Regarding software production for CIM, it is of special interest to see how specialization between software and consulting firms, computer vendors and suppliers/users of CIM systems is reflected in statistics. From among the software suppliers in the Datamation-100 list, four groups of firms were formed according to the following characteristics (see Table 1):

1. Does data processing determine the profile of the firm (yes/no)?
2. Does software production, as a part of data processing, determine the profile (yes/no)?

Each of these groups of firms is pursuing its own interest on the CIM software market and has its own opportunities for advancement. The firms of the first and second groups concentrate on the production of standard software and software tailored to users' needs, whereas the third and fourth groups offer mainly systems software for their hardware (see Figure 1).

In particular, the big firms of the second group have done pioneering work in building CIM systems. After all, 65 per cent of the investments spent on CIM in the United States comes from large complex systems

purchased by the top 2 per cent of manufacturers (Krouse, 1987).

Recently, these large CIM users have increased their standardization efforts in IS, having the ability to put pressure on IS suppliers. The activities of General Motors, the world's largest manufacturer, are well known. With the help of its Manufacturing Automation Protocol (MAP) project, an international standard for communication networks in CIM firms is being developed. General Motors is engaged in a five-year software development effort known as the C3 data pipeline, co-operating with other strategic partners under the direction of its own subsidiary Electronic Data Systems (EDS).

The example of General Motors proves that large CIM users of the second group increasingly offer software, IS services and consulting on the market. EDS, for example, aims at changing the relationship of software for General Motors to software sold to the market from 2 to 1 in 1987 to 1 to 1 at the beginning of the 1990s (Datamation, 1988).

Many hardware suppliers (third group) are also entering the expanding CIM market, combining own CIM software and offerings of other vendors to supply integrated systems. The aim is to build up a comprehensive software library for their computers, the emphasis being put on system software. Above all, the large computer vendors such as IBM, DEC and Hewlett Packard are applying CIM systems and are able to offer application software and systems integration services. The same applies to large heterogeneous companies of the fourth group, such as Siemens. However, CIM systems are only a by-product for them. In contrast, smaller computer vendors such as Prime are undergoing a transformation process into systems software and integration services companies. Through the purchase of the well-known CAD CAM firm Computervision in 1988, Prime became the second-largest player in the CAD CAM business overnight, after IBM. CIM as a product is regarded as the centre of the company's strategy.

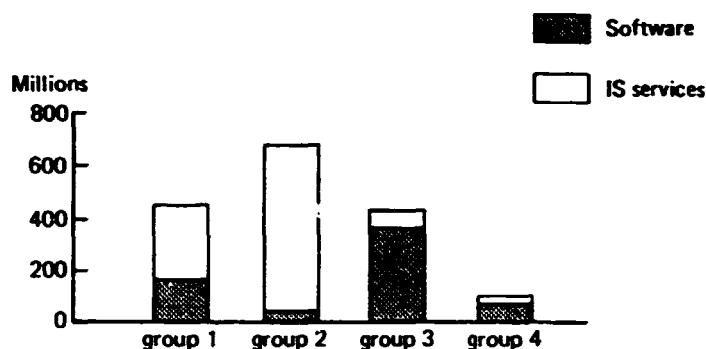
Table 1.

Groups of leading IS companies with selected representatives in 1986

	2: YES	2: NO
1: YES	1st group: Software and consulting firms Microsoft Lotus Intergraph Computervision Computer Sciences	2nd group: Big heterogeneous companies, especially suppliers of application systems, custom programming and system integration TRW EDS/General Motors General Electric Arthur Andersen McDonnell Douglas
1: NO	3rd group: Hardware suppliers IBM DEC Hewlett Packard Prime Fujitsu	4th group: Heterogeneous companies supplying systems software Texas Instruments Honeywell Emhart Siemens Philips

Figure 1.

Average IS services and software revenues
in the four groups of IS companies (1986)



Software and consulting firms (first group) are playing an outstanding part in the emerging software industry. They are proving an efficient form for software innovation transfer, trying to ensure their survival with the help of different strategies. The following are central points of such strategies:

1. Survival through growth, purchase/amalgamation of smaller firms;
2. Opening up niche markets with innovative products (e.g. AI software for CIM);
3. Strategic alliances with hardware suppliers and/or CIM systems suppliers for joint marketing;
4. Offering special services (systems integration consulting) for CIM users.

Statistical analysis of the 100 leading IS companies has confirmed that there are some essential differences between software and service companies (first group) and other firms:

- As regards the number of employees, software firms are much smaller than computer firms (third group), which in turn are on average smaller than firms of other industries;

- The average revenue per employee of software firms was about 25 per cent lower than that of other groups in the period under review;
- R&D costs per employee and net income per employee of IS firms (first and third groups) are remarkably higher than those of other heterogeneous companies;
- The share of the net income in revenues of software firms, which averages 8 to 10 per cent, is distinctly higher than the shares of other groups of firms.

These investigations prove that software and consulting firms are new economic units with specific characteristics. Table 2 compares the characteristics of hardware vendors and software vendors. Software firms cannot simply be integrated into large heterogeneous companies but require specific management methods and a long-term conception for the development of a culture of their own.

Independent software firms are best suited to transfer software technologies.

Table 2.

Comparative traits of hardware and software manufacturers

<i>Characteristics</i>	<i>Hardware vendors</i>	<i>Software vendors</i>
Principal differences	Production-oriented capital-intensive	More developmental intelligence, intensive few fixed and direct expenses, potential for much larger margins and the short-term manipulation of operations, profitability, and strategic expenditures
Personnel	Semi-skilled	Highly task-oriented individuals, vast differences in productivity
Management/ organizational differences	Hierarchical pyramids, formal reporting channels	Shallow, more participative management structures
Product	Technology-based	Knowledge-based

Source: Newman et al., 1987.

5. Strategic software research and its social co-ordination.

The strategic contradictions in software engineering cannot be solved quickly by efforts of individual organizations or by isolated improvements in the software infrastructure. For this purpose, long-term scientifically-founded and vigorous measures on national and international levels as well as the co-ordination of software strategies by society are necessary. In the highly industrialized countries, Governments and firms have managed to improve co-operation between their R&D units and the concentration of software technology. R&D has progressed considerably over the past decade. The development of software technology has reached a stage requiring new social circumstances to be created by means of large-scale strategic software technology programmes.

In the industrialized countries, many strategic software technology programmes are being realized at different levels, by corporations, alliances, and national and international communities. This "boom" reflects the

synchronization of economic processes and general trends in the development of productive forces. Strategic projects aiming at promoting software innovations may be arranged according both to the management levels and to the range of supplies of software products and services for CIM.

Figure 2 gives a survey of the strategic projects in market economy countries showing how these can be grouped in seven clusters:

1. Projects of international communities supported by a broad range of IS suppliers.
2. National projects realized by a broad spectrum of IS suppliers.
3. Projects of national alliances of corporations and research consortia.
4. Projects of corporations producing IS equipment.
5. Project of corporations manufacturing and/or using embedded IS (e.g. CIM systems).
6. Projects of small innovative software enterprises.
7. Projects of research institutions.

Figure 2. Clusters of strategic software technology programmes

SUPPLIER	LEVEL				
	International	National	Alliances of corporations	Corporation	Enterprise
Supplier of embedded IS			CAM-I MAP/TOP COS	Lockeed TRW GEC	
Manufacturer of IS and IS components	ESPRIT EUREKA	US DoD JFGCSP ALVEY		IBM TI Fujitsu	Microsoft Carnegie Group Reasoning Systems
Designer of prototypes		MIT CMU	MCC		

- MAP = Manufacturing Automation Protocol
 TOP = Technical and Office Protocol
 COS = Corporation for Open Systems
 GEC = General Electric Corporation
 JFGCSP = Japanese Fifth Generation Computer Systems Project
 TI = Texas Instruments
 MIT = Massachusetts Institute of Technology
 MCTC = Microelectronics and Computer Technology Corporation
 CMU = Carnegie-Mellon University
 ESPRIT = European Strategic Programme for Research in Information Technology

The following characteristics of these strategic programmes should be emphasized:

- Their long-term orientation (approximately 10 years),
- The long phase of preparation (numerous experts have to be engaged),
- The (international) co-operation of competitors in R&D and in marketing (R&D consortia),
- The high corporate investments into basic research,
- The combination of application-oriented basic research in different high technologies (software technology, new computer architectures, ASIC design, artificial intelligence, CIM),
- Government support through co-ordination, financial assistance and sales guarantees,
- The growing influence of software users and their increasing participation in research programmes and national and international standardization efforts,
- The orientation towards efficient software infrastructures.

The official comprehensive strategic programmes are only the tip of the iceberg. Governments and corporations have initiated many other activities for promoting software engineering. There are some fields in which an especially close co-operation between the levels can be observed including:

- The establishment of R&D centres and high-tech parks,
- Provision of venture capital for small innovative software firms,
- Tax and customs policies,
- Standardization,
- Legal protection,
- Educational policies.

6. Strategy elaboration for CIM software: Experience in the German Democratic Republic and new challenges

The German Democratic Republic's economic strategy is aimed at the development and broad application of high technologies, in particular microelectronics and CAD/CAM/CIM. In the mid-1980s, planning authorities arrived at the conclusion that an industrialized country with these

objectives could not do without a software strategy of its own.

"Robotron" and "Datenverarbeitung" are two large combined works in the German Democratic Republic, concentrating on software engineering. Many other combined works built up software engineering teams for CAD/CAM/CIM in the 1980s, which step by step are being turned into independent firms with an increasing authorization to take decisions. However, software is still a bottleneck, both in quantitative and in qualitative respects, although the software turnover has had growth rates of more than 20 per cent in the past few years.

An international comparison of indicators such as software exports and share of software revenue in GNP shows that the German Democratic Republic's software industry – and that of other socialist countries – has made headway, but is somewhat delayed in comparison with other countries with a leading position in this field (Goodman, 1987; Hebditch, 1988).

Important tasks for the next few years are:

- To lay the scientific groundwork in the field of software technology on a large scale,
- Essentially to increase the potential for basic research into software technologies, especially in the "Robotron" and "Datenverarbeitung" combined works,
- Decisively to increase the qualifications of software engineers,
- Find proportions between large, medium- and small-sized software engineering firms that are adequate to the nature of software development,
- Develop organizational forms of closer co-operation between science and production, and
- Improve the management and planning system.

All in all, it is necessary to improve the framework for research in computer science and software technology putting emphasis on the following (Merkel, 1989):

1. Co-operation within the CMEA:

Co-operation within the CMEA in software technology does not correspond to international standards exemplified by ESPRIT and EUREKA. Two conclusions should be drawn:

First, it is necessary to continue the efforts made towards the further development of the common CMEA market through the co-ordinated

improvement of national economic management mechanisms (CMEA, 1988, p. 7).

Secondly, it is necessary to increasingly develop mutually profitable co-operation with scientific organizations and firms of leading countries (for example, joint ventures); the foundation of a joint German Democratic Republic-USSR software firm was an important landmark at the 1989 Leipzig Spring Fair.

2. Co-operation between research and industry:

Owing to the short-term orientation of several economic units, it is not easy to arrange strategic co-operation between R&D institutions and industry. With the growing independence of the German Democratic Republic's economic units, there is also an increasing interest in long-term and close relationships with R&D; and the ability to make high profits on international markets with the help of original developments is being strengthened.

The mid-1980s saw initial efforts to create a framework at the macro-level for the development of an infrastructure for the software industry. This framework, which is not yet perfect, is formed by scientific societies, educational institutions, temporary management structures and expert groups, territorial structures (interest groups and user communities, organization of software markets), information and consultation centres for software, as well as state organizations.

In 1988, software strategies were elaborated both for selected combined works and for the national economy. The present stage in strategic work can be characterized as follows:

1. Strategic work has concentrated on most promising fields (systems software, application software, CIM, DBMS, software technology, artificial intelligence, etc.). Forecasting and quantitative evaluation of software technologies have not yet been integrated in strategy elaboration. The time horizon should be further extended in future strategic work.
2. The statistical database for strategy building has been improved. However, it is not yet sufficient for evaluating the level of automation attained in industrial software engineering.

3. The management of software strategy elaboration has to be further improved (ensure independence of individual combined works, independent evaluation of strategies, provision of strategically relevant data, strong comparison with the advanced state of the art expected).
4. An efficient strategy has to offer favourable opportunities for development to the software industry; it should actively contribute to the formation of relationships of production that are adequate to the specific characteristics of software as a productive force.

Further research work is necessary in the following fields: price fixing for software, combining the advantages of large-, medium- and small-sized software engineering firms, economic mechanism, software protection, efficient forms for integrating science and production.

As a whole, considerable efforts are necessary to establish a sound methodological foundation for strategic work.

Intensive work is being carried out in the German Democratic Republic to combine methods of economic management with administrative methods (balancing as a form of social co-ordination between software engineering companies and avoiding parallel developments). In so doing, emphasis is put on the extension of market relations to the whole information and knowledge industry and their integration into the socialist planned economy (Haustein, 1989).

To sum up, the main problem is to organize the whole social environment in accordance with flexible production as the new organizational mode of production (for a more comprehensive discussion see Weber, 1989). Obviously, the economics of "intellectual" products differ essentially from the economics of traditional products (Makarov, 1987). Our future research efforts will concentrate on the socio-economic evaluation of intellectual production (in particular, intellectual original production, software, artificial intelligence), investigations into flexible production, software economics as an important component of the economics of CIM as well as on the methodology for elaborating innovation strategies.

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PART FIVE

STANDARDS FOR CIM

STANDARDS FOR MANUFACTURING

by M. ACTIS DATO, Digital Equipment, CIM International Engineering, Torino, Italy

The need for standards

CIM applications are considered by the general public as one of the most significant symbols of our times and as outstanding milestones in technical progress. Insiders may share such an enthusiasm, but certainly are keenly aware of all the difficulties that have been painfully overcome for each of the accomplishments.

According to a report from Ingersoll Rand, in the United States 80 per cent of CAD/CAM, FMS and integrated DB implementations, and 60 per cent of CAD, MRP and DNC implementations have failed to reach their goal.

Measurement of success is an ill-defined matter, but on no account can such a record be considered brilliant.

It must be analysed keeping in mind that the most basic CIM function, integration, is performed according to each individual case by organizations having very different characteristics, strategies, objectives and constraints.

The systems integrator (SI) can be a machine-tool manufacturer who has added to his original know-how to become a problem solver rather than a supplier of off-the-shelf products; or can be a manufacturer of device controllers that has stumbled on CIM issues trying to connect the individual machines in a network; the SI can also be an IT systems vendor who is eager to get the overall responsibility for a project, but subcontracts some of the tasks.

In all the above cases there are two conflicting cultures: one process oriented and traditionally related to electromechanical know-how, the other IT-oriented.

Each CIM project is a different story, but some features are fairly constant.

The lack of involvement of the IT function in the initial phases of the project is particularly frequent and dangerous. This leads to underestimate its costs, and to disregard problems and opportunities entailed by integration. A system-oriented attitude early in the

project can be a key factor for success, assisting the final user to derive from his needs, often unexpressed and perceived confusedly, as set of precise requirements.

Lack of communications between engineers and computer scientists can continue during the project's life, so that modifications to the physical process are not accompanied by the corresponding changes in the control system; in some cases, they diverge to the point that the sub-projects can be considered virtually unrelated. Inconsistencies increase during time, and can be detected only in the field, late in the life-span of the project. Moreover, a tight budget, caused by the late involvement, does not allow corrective actions.

Another problem, and not a minor one, originates from the fact that typically the field test of the control system is the last activity in the project that can be performed only when the electromechanical components are working properly. Delays and inefficiencies from the most varied origins, which were overlooked in earlier stages, become suddenly evident because of their effects only in this phase.

Usually the IT department is charged with the faults, according to the rule that: "when something goes wrong the blame is on the one who was nearest when the discovery was made." In such a way the IT department becomes the scapegoat for faults that more properly should be blamed on the whole organization.

In the long run the situation will improve as a result of the increasing diffusion of the new culture; for today and for the near future, all SIs can only try to minimize their exposure to risk.

Independently of how SIs are classified, this leads to a continuing endeavour to shrink development lead times, using, at least partially, products from previous experiences.

Conversely, it means also the attempt to implement products that can be used on several occasions.

This approach, in addition to clear advantages in terms of lead times and costs, allows to put a remedy to the uncertainties entailed by incomplete

specifications, their late delivery, and to variations to the original design, whichever cause may need to be rectified. Moreover, as a prerequisite to rapid prototyping, it can have a crucial role in the initial phases of the project, when it is necessary to assess the true problems and expectations of the client.

Not many can boast significant accomplishments in this area.

The difficulties arise from different causes: on the one hand the problem is intrinsically complex because the applications tend to differ significantly from one to another, and because technical, organization, cultural aspects are intermixed.

On the other hand technical improvements make the proven solutions obsolete in a short time, leaving insufficient time to recover the capital investment. Finally the lack of widely accepted standards entails an exceedingly fragmented supply.

The SI can influence, marginally, only the last of the three causes of inefficiency. Unfortunately even this task is neither simple nor easy.

The SI can have two basically different attitudes with regard to standards: he can either passively wait for a norm to be defined and widely accepted, or he can get actively involved in its definition.

The speed of innovation is such that the first strategy has no chance of success. It's likely that a norm, when formally accepted as such, will be obsolete. The "window of opportunity" to exploit the potential of a standard-based product is so narrow that the product must be ready well in advance of the formal release of a norm.

Active involvement in the preparation of standards is therefore mandatory.

Players and trends

The players in the area of standards are so numerous that their simple listing is well beyond the scope of this paper.

For a description of the standardization bodies, and a thorough discussion on their scopes and operating procedures, we recommend the book by C. Cargill (Bibliography).

Suffice it to say here that standardization bodies can be grouped in the following categories:

- International.
 - ISO (International Organization for Standardization)
 - IEC (International Electrotechnical Commission)
 - ITU (International Telecommunication Union)
- Regional. Among them:
 - ECMA (European Computer Manufacturers Association)
 - CEN (Comité Européen de Normalisation)
 - CENELEC (Comité Européen de Normalisation Electrotechnique)
- National. For example:
 - BDS (Comité de la qualité auprès du conseil des Ministres) – Bulgaria
 - ANSI (American National Standards Institute) – USA
 - DIN (Deutsches Institut für Normung) – Federal Republic of Germany
 - AFNOR (Association Française de Normalisation) – France
 - BSI (British Standards Institution) – United Kingdom

On the technical side the most significant developments in recent years are a consequence of the growing complexity of the issues that standards raise.

The industry standard is focused on the potentialities perceived by the provider industry; the system profile defines the attributes which a specific user group has standardized. The bridge between these two groups comes with the addition of the functional profile, which simultaneously describes a set of functions extracted from the industry standard, and a set of functions required by a larger class of users than is represented in the more precise system profile. In other words, it translates the potentiality of an industry's capabilities in a certain area into a set of functions from which users can begin to construct a more specific system.

The functional profile exists in a limbo between provider's perceptions and user needs, an area of uneasy co-operation where the providers discover if they have anticipated user needs correctly, and users can find out if what they need is within the scope of what the industry can provide.

Further discussions on this issue can be found in the book by C. Cargill cited above.

A workplan for standardization activities

An obvious step for an organization that wishes to get involved in manufacturing standards is to join the ISO TC 184 committee, whose charter is "Standards for Industrial Automation Systems."

It is also the place where difficulties begin, because it is composed of 5 subcommittees and some 20 working groups, each with its own formal structure and each meeting at least twice a year.

If a choice is not made, merely to be present at the meetings entails a workload not far from a full-time job. Such a commitment is not enough: IT standards, which are essential to integration, are processed elsewhere. TC 184 simply sees, after some delay, their projections in the realm of automation, and provides little contributions to their definition.

The relevant work is carried out in JTC 1; it includes areas such as languages, communications, and databases, that constitute the core of CIM, but that at the same time have by far a more general interest and impact.

The involvement in such activities requires correspondingly a greater workload compared with the one required by TC 184. It can be measured, in terms of documentation produced, by a ratio of 5 to 1.

And that is not all: other committees, such as IEC65, have gradually increased their scope to include shop-floor communications, a basic building block in CIM architecture.

Maybe the SI is stubborn enough and is able to overcome the above difficulties. This does not mean he has solved all his problems: after a while he will discover that the standardization committees are places where formal decisions are made, but that a lot of work, technical and not technical, is carried out behind the scenes in the so-called "feeder organizations." Like every other club, according to their nature, they can be very open or very closed to new entrants.

The SI at this point might well change his attitude towards standards, considering several drawbacks and unresolved issues:

The activity does not lend itself to being quantified and be measured in terms of return of investment; consequently, the issues tend to be dispersed among several loosely related bodies, and there are great opportunities for participation of individuals having the most varied goals, personal as well as industrial and technical.

For the returns to become actual, a mechanism must be found to transfer the results from the standardization activity to everyday working procedures. If an effective osmosis cannot be achieved, this could be the most difficult task of the whole process.

Eventually a vicious circle emerges: line managers develop a deep conviction that standardization is just a different word for parasitism, and tend to avoid all direct involvement. Conversely the individuals in charge of standard activities, feeling their worth and importance not adequately understood, tend to entrench themselves in a world of their own, adding to the impression of an unproductive activity.

A case study: the cell controller

The concepts in the previous paragraph can be better realized if seen in the context of an actual development activity. A manufacturing cell controller offers several appealing features to illustrate a likely course of activities.

The first difficulty is the definition of the controller itself: there are at least three committees working on this issue, and their conclusions are not necessarily consistent.

When a definition is selected, the number of the areas where standards can be applied is overwhelming: in the software area alone there is the user interface, the application itself, the set of tools and services that constitute the application platform, the cell data base, the product and process description, and all the communications: to the field (fieldbus, to the machine controllers, to the peer cell controllers, to the host computer, to the computers in the design and manufacturing engineering departments).

In each of the areas the number of existing, emerging or proposed standards is impressive: in the user interfaces area alone, taken as an example, at least all the following standards are competing and supplementing each other: GKS, GKS-3D, GKS-9X, PHIGS, PHIGS+, X-WINDOWS, PEX, CGM, CGI. A choice must be made, based on incomplete

and unstable information. Which is the safe (or the least risky) bet?

Focusing the attention on communications in manufacturing environments, MMS on top of the ISO OSI stack seems to be the emerging standard.

The specifications have just been approved, and implementations are starting to come to the market. Many important issues are still to be agreed upon (namely companion standards and application interfaces). The nonconformant installed base is huge, as well as the investments it entailed.

The basic question here is: "at which rate will the market develop?" The answer probably lies within the strategies and the behaviour of the machine controllers manufacturers, and within their user's preference.

MMS is composed of two parts.

The first (MMS CORE, ISO IS 9506) defines the general framework and rules to attain device inter-operability, in abstract terms, valid for all CIM.

The second (companion standards - CS) details the semantics for every class of devices.

The first part is an International Standard. Companion standards are being discussed, and currently are at various stages of development.

CSs try to fulfill all the actual communication needs of several types of operating machines. Their goal is very ambitious; in their most complete form they must include all the needs in all operating situations. If a single CS is defined for every device type it must include some features that are required only in a minority of cases, and are an unnecessary burden in all the other (e.g. program up- and down-loading capabilities are not needed if the application requires simple monitoring of the plant).

To avoid this pitfall, each CS will be structured in profiles, each corresponding to a class of applications. The complete CS will have predefined "cuts"; for each class of applications only the relevant features will be implemented. Of course full up-and downward compatibility between different classes of the same type of device is not guaranteed.

Our personal opinion is that ISO 9506 is a document of high quality. Even disregarding the standards issue it maintains its worth; it might well be titled "rules for correct programming the interface of operating

machines." However the success of MMS can be endangered by three types of problems:

1. The culture of today's machine programmers.

Most shop-floor programmers are not familiar with the concepts of MMS, which requires a process of abstraction. Presumably the situation will continue in the future, under the pressure of labour cost.

A significant effort must be devoted to develop a user friendly, foolproof user interface, that makes direct reference to the actual objects and operations on the shop floor (no abstraction). It is not sure that the task is feasible, and on what terms.

2. The sophistication of the machine control units.

For CSs the control units must support a highly sophisticated user interface and a whole set of different protocols (the classes of applications). Normally there is not much fat in control units, and cost is the single most important evaluation parameter.

The cost entailed by the added requirements might push a conformant control unit out of the market.

3. CSs might proliferate out of control (the rampant breeding of CSs).

A standard which is applicable in only one case is not a standard any more. A frequent situation will be: the considered application is only partially covered by CS class 1; some other aspects are covered by CS class 2; CS class 3 has all it needs, but it has too many unrequired features. A new CS, class 4 needs to be developed.

Moreover, technical advancements in the process areas can force frequent changes even within the same class, and it is well known that the process of updating a standard is slow.

The variety and volatility of the features of the process world must not be underestimated; probably the first partial successes will be achieved in well specified market niches, still to be identified. Good candidates are communications between cell controllers and host computer, because there is already available a significant processing power, or communications with controls such as "Pyramid" from Allen Bradley, built around a "real" computer.

A partial success has been attained, outside the MMS framework, in the plastic industry.

As a conclusion probably the development and acceptance of MMS and CSs will be rather slow. Probably more than a standard in the strict sense, it will develop into a set of rules which do not automatically guarantee interoperability, but facilitate interfacing greatly.

The SI who wants to develop an MMS communication layer, facing several uncertainties, will try to reduce his exposure to risk.

He should require configurable interfaces towards the application (the still undefined companion standards) and towards the lower layers (what happens if the device suppliers choose to develop MMS on a simple, proprietary lower stack?).

He should try to define as data all the information he can, so that the code becomes robust in relation to unstable specifications.

He should also try to use the same development tools for communications as well as for applications: when talking of CSs the distinction is in any case blurred, there is an obvious advantage in terms of the learning curve, and on many occasions it has been proven that methods initially designed and tested in the computer science realm can be successfully applied in industrial engineering as well.

The requirements are strict and their fulfillment opens questions which must be dealt with.

Many of them will become apparent only after a thorough examination, but even at first glance the issue of the applicability of Estelle and Lotos is relevant.

It must be verified where and when they can be used: for the application, for the MMS layer, for the lower layers protocols, for device interconnection; their scope must be determined: test sequence generation, specification, requirement analysis, watchdog checking.

The two methods are competing, addressing the same issues with different approaches: their relative breadth of applicability is a matter of debate.

It is also worth investigating the interface between MMS and the software platform provided by the IT vendor.

For example RPC is a *de facto* standard, and a *de jure* ECMA standard, for certain types of distributed applications: its compatibility with the envisaged MMS implementation is of the utmost importance.

If the SIs consider the opportunity to use a vendor supplied MMS, the necessity arises to assess to which extent this is really a product conforming to standards: in an extreme case it could well be a proprietary product, labeled as standard. Even if the vendor supplied MMS is fully conformant to the standards, the SI has a need to assess how easily it can be interfaced to the application, or how easily a layer equivalent to a companion standard can be interfaced.

In front of the volatility and fragmentation of the user market it is worth considering the development of a system to generate application protocols (to be layered on top of a standard MMS layer?). The user should describe and specify his own inputs using an appropriate tool, e.g. ASN.1, together, if necessary, with some other formalism. The system checks the conformance to MMS rules and produces a code that interfaces the standard layer.

The concept of protocol generator keeps its validity also if the standardization aspects are disregarded. The resulting system is a product in his own right, based on the soundness of the concepts described in IS 9506

The SI might want to use such a tool, developed for MMS, also in cases where MMS is not applicable, for example for interworking with devices having proprietary protocols. This means that the tool must be able to describe and model a wide range of protocols, down to the lowest ISO layers.

There is only one way to find an answer to all the open issues that the development of a product conforming to standards entails: experimentation.

But experimentation is difficult by all means, and sometimes it requires an intimate knowledge of proprietary software.

Moreover it is risky in terms of cost and time versus expected results, and the investment must be recovered in a very short time, because everything becomes obsolete so quickly, following the improvement of hardware performance.

Probably the successful SI will choose to focus on the tasks which are unique to his role, that is to ensure that a proper interface is developed for the components among themselves and towards the whole enterprise system.

In that case he will select his suppliers based on their compliance to his goals.

One of the most significant parameters for the choice becomes the vendor's support for standards, considered as a milestone in his own strategy, and not a user-driven external constraint.

Conclusions

Hardware developments have an overwhelming influence on the performance that the standards must be able to support.

Products conforming to standards have therefore a short life span, and their approach to the problems tends to appear rather fragmented: because of the increasing integration issues, which were originally unrelated, require compatible solutions.

Standards activities are inherently risky, because developments must be undertaken well in advance of any formal decision by the standardization bodies. Moreover they can represent a major investment in terms of time, human resources, cost.

In short, the development of products conforming to standards is a bet the SI can seldom afford to make.

What the SI should do is to select IT vendors based on their commitment to standards.

The IT vendor, in turn, should make his choices on matters related to standards on the basis of a wide and deep experimentation background. This will make it possible for products to appear on the market early and to have a better (native) performance.

Notes

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