CIM: REVOLUTION IN PROGRESS

W. HAYWOOD, Editor

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IIASA's Computer Integrated Manufacturing Study: Publications

IIASA's CIM study will be reported in five major volumes. Four of these, Volumes I through IV, will be published by Chapman & Hall (London, UK). The fifth will be published by Harvard Business Press (Boston, USA).

The first four volumes will appear as a set and the anticipated publication date is early 1991. The fifth volume is to be published at approximately the same time.

Computer Integrated Manufacturing, Volume I:
Revolution in Progress
R.U. Ayres
(Chapman & Hall)

Computer Integrated Manufacturing, Volume II:
The Past, the Present, and the Future
R.U. Ayres, W. Haywood, M.E. Merchant, J. Ranta,
and H.-J. Warnecke, eds.
(Chapman & Hall)

Computer Integrated Manufacturing, Volume III:
Models, Case Studies, and Forecasts of Diffusion
R.U. Ayres and W. Haywood, eds.
(Chapman & Hall)

Computer Integrated Manufacturing, Volume IV:
Economic and Social Impacts
R.U. Ayres, R. Dobrinsky, W. Haywood, K. Uno, and
E. Zuscovitch, eds.
(Chapman & Hall)

Computer Integrated Manufacturing, Volume V:
Managerial and Organizational Implications
J. Ranta, J.E. Ettlie, and R. Jaikumar
(Harvard Business Press)

Further information can be obtained by contacting Mr. Robert Duis, Manager, Publications Department, IIASA, A-2361 Laxenburg, Austria.

FOREWORD

The Final Conference of the IIASA Project on Computer Integrated Manufacturing was held at the headquarters of IIASA in Laxenburg, Austria, from the 1st to the 4th of July, 1990.

The Conference itself was co-sponsored by the Ford and Alfred P. Sloan Foundations, though much of the earlier research work owes its existence to funding by the Finnish Sitra Organization and the American National Science Foundation. In addition to these primary funders, much of the work carried out by individual researchers was funded by their own governments, research institutes, etc., this included major inputs from Japan and Czechoslovakia.

The aim of the research was to examine CIM from various perspectives including: technological characteristics, the diffusion process, managerial and organizational aspects, and the social and economic implications.

The Conference was attended by 105 people from 22 countries, including representatives from the OECD, UNIDO, the ECE, and the ILO. Of these participants 28 came from Eastern Europe and the rest from Japan or Western countries.

This Volume contains selected papers presented at the Conference, and transcripts of key parts of the policy discussion. The papers are organized in the following way:

Part 1. Overviews
Part 2. Strategies and Models for CIM
Part 3. CIM Diffusion Studies
Part 4. CIM Technologies
Part 5. Organizational and Social Impacts
Part 6. Keynote Policy Panel Discussion
Part 7. CIM Implications for Industry and Government.

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The IIASA CIM Project

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The IIASA CIM Project

SUMMARY

The concept of computer integrated manufacturing (CIM) originated in the 1960s. The essence of that concept was that the new-found powers created by the advent of the digital computer, as a systems tool, possessed potential to be harnessed to integrate all the different elements of manufacturing in such a way that manufacturing could be operated as a system--one which, by virtue of the unique capabilities of the computer, could be flexibly automated and be self-optimizing in real time online. The reduction of that concept to practice in industry has been a slow and painful process and one which is still far from complete.

Initially, and throughout the 1970s, that development and implementation of CIM in industry progressed quite slowly. Most manufacturing companies were heavily engrossed in applying computer technology to flexible automation of isolated elements ("bits and pieces") of manufacturing, creating "islands of automation", with little or no interest in, or even understanding of the need for, overall integration of those bits and pieces into an overall flexibly automated, adaptively-optimizing manufacturing system. With no interest in, or understanding of, the need for future integration of the islands of automation, these companies were, in effect, erecting barriers of incompatibility to future integration of their islands of automation.

Had a cooperative international project to elucidate the technological, economic and social potential of CIM and how this might be most effectively realized in practice--a project similar in principle to the current IIASA CIM project--been carried out in the early 1970s, it could well have done much to circumvent the retarded development and implementation of CIM in industry, and the "islands-of-automation", blind-alley syndrome described above. Unfortunately, however, no such organized international effort took place, and so the "CIM doldrums" continued throughout the 1970s.

However, by the 1980s that situation began to change, with manufacturing industries throughout the world gradually beginning to become acutely aware of the tremendous competitive advantages which could be imparted to a manufacturing enterprise by overall automation, optimization and integration of its total system of manufacturing. Further, by the mid-1980s, industry had become fully aware that such integration must

encompass not only the technological elements of its manufacturing system--product design, production planning and control and factory (shop floor) automation--but also the business and managerial elements of that system--strategic planning, finance, human resources and marketing--to create a computer integrated manufacturing enterprise. This awakening on the part of industry has resulted in the emergence of a powerful new trend and commitment on the part of manufacturing industries throughout the world--one toward *realistic* and *substantial* accomplishment of *full* computer integrated manufacturing in their individual enterprises, with all of its capabilities for overall integration, automation and optimization of the operation of such.

The bulk of this awakening and commitment of world manufacturing industries has been occurring in just the past few years. It is my firm belief that the very fact that IIASA, with its worldwide prestige, began, during that period, to highlight the fact that a new industrial revolution was being spawned by CIM (and, in consequence, to carry out a major international study to provide understanding of its technological, economic and social events and consequences), has, in itself, been an important factor in that awakening and commitment by world industries. However, now that the study has been completed and the full depth and power of its findings can be appreciated, it seems very evident that understanding of those findings by world manufacturing industries can, at this critical period of the launching of the revolution, provide substantial help, guidance and incentive to such in accomplishing successful execution of the very difficult and complex tasks that must be undertaken to develop and implement realistic and substantial CIM capabilities in their overall operations.

Overall, the completed study provides a tremendous wealth of understanding of the technological, economic and social realities and consequences of the emerging new industrial revolution spawned by CIM. Further, this understanding is in a form that can be readily appreciated and absorbed by industry. It documents the powerful strategic benefits which CIM technology has already been able to demonstrate in practice, even in its current somewhat rudimentary form. In addition, it provides understanding which manufacturing industries can apply to plan, develop and implement CIM in such a manner as to realize to the greatest extent possible, these, plus other yet-to-be realized, strategic benefits, as they carry on the continuing, long-term reduction of CIM to practice.

The study's principal conclusions also have major implications for manufacturing industries. Of these, the ones which seem particularly cogent are, briefly paraphrased, as follows:

1. Productivity of capital and labor can be expected to increase sharply in the 1990's in those countries which are already using CIM technology most effectively.
2. Competitiveness in the manufacturing industries will increasingly depend on the quality of a firm's integration and communication software.
3. The *software* component of capital investment in manufacturing will continue to grow in importance relative to the *hardware* component.
4. It is very difficult to convert a traditional Taylorist-Fordist manufacturing plant to CIM by simply installing sophisticated new equipment.
5. It appears that, under the impact of the increased flexibility and *economies-of-scope* (versus *economies-of-scale)* provided by CIM, a trend is developing toward more dispersed, decentralized production systems within industrialized countries, with many more small plants, located near markets, and with de-emphasis of the recent trend in industrialized countries of moving plants off-shore to low-wage countries.

Such conclusions as these, combined with the wealth of related detailed findings of the overall IIASA study, serve fair warning to the manufacturing industries of the world that a revolutionary, wholly new way of operating a manufacturing enterprise (be it large or small)--a way offering powerful strategic and competitive advantages to such enterprises--is now coming into being and already beginning to demonstrate such power. Those manufacturing enterprises and industries which fail to heed that warning and to institute appropriate action to take full advantage of this new approach to manufacturing will, to say the least, be operating at an increasingly severe disadvantage as this irreversible revolution, now entering its period of most rapid growth, rolls ahead! Those which do heed this warning, and take action accordingly, can find, in the results of the IIASA CIM project, substantial guidance and help in support of their efforts to achieve such advantage.

CIM: Driving Forces and Applications

by

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Hypotheses

The IIASA technology assessment of computer integrated manufacturing (CIM) began four years ago. It was prompted by several hypotheses:

a. complexity versus human error

b. flexibility (for suppliers)

c. scope versus scale economies

d. new manufacturing possibilities

The first hypothesis was prompted by the observation that computers are much better than humans at bookkeeping and keeping track of lots of numbers. This means computers can be uniquely helpful in managing complex situations. Manufacturing has become enormously more complex over the past two centuries. What was simple enough to be comprehended by a single individual in the days of cottage industry has now reached a stage of complexity that is almost unimaginable. In the first place, the number of parts involved in a typical manufactured item has increased many-fold (see *Figure 1*). The graph tracks typical trends in part-number for items produced in several scales. Note that batch sizes have also increased dramatically over the same period, from a few thousand units produced over a period of years (e.g., Eli Whitney's famous musket manufacturing contract in 1799) to million of units per year.

Why does complexity matter? Because complexity increases the chances of a human error, leading to a defective product. This is part of the "quality problem" many manufacturers have noted. Products and manufacturing processes have changed in the past two centuries, but humans remain essentially the same, except for what they are taught in school and on the job. But humans are biologically limited. They cannot work at repetitive tasks without making errors. The tendency is in-built. "To err is human" as Shakespeare said. But errors in complex systems are dangerous and, basically, intolerable. The cost of quality control - which means error detection and correction - are rising as a fraction of total cost. (And many of these costs are paid only by the final customer - as when a defective aircraft or space-shuttle crashes).

The second of our four initial hypotheses was that greater flexibility is needed in manufacturing technology to avoid the conflict between minimizing unit cost and facilitating product change (*Figure 2*). This conflict has become known as the "productivity dilemma" (Abernathy) or the "productivity paradox". The problem is, simply, that large fixed investments in dedicated "hard" automation are also a barrier to change - to the extent that the fixed capital is inflexible and not convertible to manufacture a new or improved version of the product.

The third initial hypothesis was that economies-of-scale are being replaced by economies-of-scope as drivers of economic growth. This virtually follows from the previous hypothesis. (Economies-of-scope are nothing more than the ability to convert fixed capital from one purpose to another). The "old" paradigm of economic growth featured a cost-price driven mechanism (*Figure 3*).

This mechanism is entirely dependent on economies of scale. Increased demand for variety in products (encouraged by higher incomes and general satisfaction of basic needs in most western countries) is making this mechanism for growth increasingly irrelevant. See (*Table 1*) and (*Figure 4*).

One does not get economies of scale without standardization. Is there an alternative to economies-of-scale that would have the same impact on growth? We think perhaps there is, along the following lines illustrated in *Figure 5*.

The key to the suggested "new paradigm" for economic growth is that increasing flexibility progressively reduces the cost differential between customized and standardized products. The smaller this differential, the greater the demand for diversity and, hence, flexibility. But this process, in turn, leads to further improvements in the manufacturing process, generating savings

Table 1. Examples of variety increases.

Ford "Model T"	1 model
Seiko Watches	> 3,000 models
IBM "Selectric" Typewriters	55,000 models
"VAX" Computers	all different
Westinghouse Turbine Blades	> 50,000 designs
KAMP Electrical Connectors	> 80,000 types
Sears Roebuck Stores	> 50,000 items in stock

in both labor and capital and – in effect – restarting the traditional cost-driven engine of growth. One purpose of the study was to explore this idea further.

A fourth hypothesis is that extraordinarily rapid improvements in the basic "enabling" technologies of telecommunications, micro-electronics and computers have created new possibilities for manufacturing that simply did not exist before. In each case the rate of technological progress is not only high – one or more orders of magnitude per decade – but there are indications of acceleration since 1980.

CIM arises from the confluence of supply elements (technology) and demand elements (flexibility, quality, variety).

CIM: The Next Industrial Revolution

The basic thesis, then, is that CIM is the next stage in industrial evolution. Indeed, it is so fundamental in nature and so potent in its effects that we can designate CIM as the next (third) "Industrial Revolution". In brief, the first I.R. (c. 1770–1830) was the period of adoption of steam power to replace water power and horses as prime movers. In particular, the new power source was used to drive the newly developed metalworking machine-tools. The second I.R. (c. 1880–1910) was an extension of the first. Electricity made it possible for centralized prime movers to deliver power to decentralized users. Internal combustion engines made power truly mobile (and led to heavier-than-aircraft, and the final displacement of horses). In these simplified terms, the third I.R. (c. 1985–?) is the adoption of computer power in discrete-part manufacturing. After decades of anticipation, computers and "smart sensors" are finally beginning to substitute for human brains in the factory, as well as the office, at least for simple repetitive tasks. These are many tasks where the human worker does not actively use intelligence, except to convert a flow of information from one form to another.

But this picture is oversimplified because it omits a number of key dimensions of the manufacturing problem. A more revealing characterization of industrial evolution would be that the preindustrial period of craft guilds and cottage industry was coming to an end in the late 18th century, hastened by the Napoleonic wars. The first stage of mechanized manufacturing could be called the "English system". It applied the new power-driven machines to the old methods of production, except for increased specialization and deskilling of labor. A more revolutionary change for manufacturing was the next stage, known as the "American system" (1850–1920), which was developed initially in the arms industry of New England and subsequently exported around the world. It emphasized product standardization and interchangeability of parts, even when this could only be achieved at the expense of accuracy and precision of fit.

The next phase (1920–1960) was the heyday of "scientific management", developed and promoted by Frederick W. Taylor and adopted most enthusiastically by Henry Ford. This was, in some ways, the logical extension of the American System, but it emphasized mechanical integration (e.g., assembly lines, transfer lines), hierarchical structure, vertical integration, cost-accounting and extreme division of labor into "optimized" tasks. Widely attacked by labor as "exploitative" and "inhuman", its major weakness was (and is) its faulty presumption that optimization at the task level results in optimization at the firm level. This was not clearly recognized by managers until much later (if, indeed, it has yet been recognized). But by this time organized labor (in the U.S. and U.K. especially) has adopted the key idea of Taylorism - detailed job specifications - as a convenient means of assuring job protection by contract.

The pre-CIM era (1960-1985) can be characterized by the rise of many new techniques (e.g., SQC, TQC, GT, JIT) and the application of computers to many individual functions. For instance, one might mention programmable machine tools (NC/CNC), computer-aided design (CAD), computer-aided scheduling and planning (MRP), etc.

In this historical context, then, CIM can be seen as the phase of functional integration, or "putting it all together". The emphasis is clearly on quality, flexibility and time-saving (rather than labor saving or cost-minimizing). This means we can expect more emphasis on decentralization of authority, "team approach" and "networking".

It is interesting to summarize this historical view, by borrowing from a fascinating case study by Prof. Jaikumar of one firm that has survived for 500 years since the preindustrial era, manufacturing essentially the same product. The product is small arms, and the firm is Beretta, of Italy. Key changes are summarized graphically in *Figure 6.*

It is tempting to believe that the Beretta experience may be an indicator of what can be expected in the future from other manufacturers. Gross output has increased enormously, of course. The overall increase in productivity since the pre-machine period is close to 500-fold. Yet absolute employment in manufacturing actually increased significantly until around 1950, when the first cuts occurred. Since then, direct employment in manufacturing has dropped by a factor of 10 (from 300 to 30), and the ratio of workers per machine has dropped from 13:3 to 1. Meanwhile the ratio of off-line workers has grown continuously, from 13% in 1867 to 67% today. It is especially interesting that the early gains in productivity clearly owed a great to the design standardization that occurred between the English period and the American period. Recent gains in productivity obviously owe nothing to standardization, since product diversity has been growing, but owe quite a bit to the dramatic quality improvements, as reflected in the drop in rework percentage from 80% in 1800 and 50% in 1867 to the present remarkable level of 0.5% - far below the level considered satisfactory by most companies today.

Technology

It is appropriate, now, to delve a little deeper, beginning with the technology of CIM. It is convenient to group technologies into three categories, viz. enabling, transitional and central to CIM.

Table 2. Technology.

ENABLING

*Semiconductors
*Computers
*Telecommunications

TRANSITIONAL

*NC Machines
*Controls
*Robots

CENTRAL TO CIM

*CAD/CAM
*JIT/MRP
*LAN
*FMS

As regards the enabling technologies (already mentioned) I have already pointed out that the rate of change is very rapid, and there are indications of acceleration since 1980, vis. a vis, telecomms (*Figure 7*), microelectronics (*Figure 8*) and computers (*Figure 9*).

It is not possible to discuss all of these in depth, but as a matter of interest, let me quickly summarize the available data as regards diffusion in the major industrial countries with regards to NC/CNC (*Figure 10*), robots (*Figure 11*) CAD (*Figure 12*) and FMS (*Figure 13*).

The only comment I will make at this time is that the diffusion of NC/CNC machine tools is surprisingly uniform (contrary to some press stories). Japan leads significantly in the diffusion of robots, and to a lesser extent in the diffusion of FMS, for reasons there is no time to discuss now. The U.S. has an equally big lead over Japan in the use of CAD, which may surprise some readers.

However, FMS is worthy of more detailed discussion. This is only partly because of the heavy emphasis on FMS in this project. It is, in some sense, the "missing link" between programmable automation at the machine level and CIM. An industrial archeologist a century from now may think of FMS (if the term is still used) as the necessary transitional stage, but hardly an end in itself. What is FMS? It is a set of CNC machines, controlled by a single (mini) computer and linked by an automated materials handling systems, designed to produce a family of relatively similar products, (*Figure 14*). There are distinguishable subspecies, such as FMS for cylindrical parts, FMS for "prismatic" parts (such as motor housings), FMS for sheet metal parts, flexible assembly systems (FAS) for PC boards, etc.

The benefits of FMS vary greatly from case to case. There is usually a sharp reduction (75% or more) in direct labor. In some cases, there are even capital savings (as compared to conventional transfer lines). Capital savings can also result from sharp increases in machine utilization. Conventional manufacturing systems use machine tools for their primary purpose (cutting) rather inefficiently, (*Figure 15*). For typical U.S. job shops, only 6% of time is used for productive work, on average, rising to 22% for large-scale high-volume producers. Because of this, there are significant opportunities for increasing machine utilization (*Figure 16*) and it follows that capital productivity in the manufacturing sector may soon begin to increase.

But, surprisingly, other benefits may be more important. These include shorter throughput times, less floor space, less work-in-process (inventory), and the ability to produce a variety of different parts with minimal set-up time (*Figure 17*). Indeed, reductions in throughput time are typically dramatic – often from weeks or months to days or hours.

Summarizing the benefits now being experienced by FMS users, which we expect to spread eventually to entire factories and firms.

Table 3. Benefits of CIM to firm.

Output per month	Fixed (normalized)
Number of machines	Down 50%
Machine utilization	Up > 100% (to 80%)
Direct labor (online)	Down > 75% (1 man per 3 machines)
Capital cost (mostly software)	Up 50–100%
Floor space	Down 50%
Variety	Up (to 00) (Lot size = 1)
Inventory of W.I.P.	Down to 0
Lead time (order > delivery)	Down (to days)
Changeover time	Seconds
Quality of products	Up (Reject rate > 0)
Product life cycle	Shorter (50%)

Assume, for purposes of argument, a fixed level of demand for the product, ignoring, for the moment, the fact that many firms have adopted FMS to increase capacity and market share. The number of machines on the floor will drop by half, or more, because each machine will be engaged in productive work much more of the time – including unmanned third shifts and weekend hours. "Direct" (on-line) labor will drop by up to 90% and total labor by 75% or more. Inventory will drop to nearly zero, and floor space needed will fall sharply, both because of the need for fewer machines, and less storage space. Set-up time, changeover time and order-to-delivery time will also drop sharply. On the other hand, product variety will rise sharply, and the frequency with which new products are introduced will also increase.

Finally, product quality will improve. Indeed, the possibility of achieving (or at least closely approaching) zero defect rates can finally be considered realistic.

Impacts of CIM

What of the impacts on business and the economy? As regards the first, I can only summarize briefly, but the main points are worth sketching quickly. First, is the end of the age of "Taylorism" (or, as some have called it, "Fordism"). This means less hierarchy, more networking, less vertical integration, more of the "team" approach, and so on. Second, manufacturing is finally being seen as a "system", amenable to the "systems approach". Joseph Harrington was one of the first to emphasize this idea. One key element of such an approach, emphasized especially by Elikaya Goldratt, is the need to identify and eliminate bottlenecks in the flows. The well known philosophy of "Just-in-Time" delivery pioneered by Toyota, can be regarded in this light. In the future it will be increasingly necessary to identify and eliminate bottlenecks in the information flows, as well as the material flows.

There is a controversy over whether the "human-centered" approach (exemplified, perhaps, by Scandinavian, West German and Japanese firms) is more effective than the "machine-centered" approach ascribed to U.S. firms where Taylorism was perhaps more entrenched. This is a false dichotomy, inasmuch as a CIM system can hardly operate without machines, nor can it function without humans. To achieve low defect rates, it remains necessary to eliminate humans from repetitive jobs where human error can lead to defective parts or assemblies. On the other hand, human talents are irreplaceable for non-routine functions like design, engineering, marketing, planning, diagnosis, trouble-shooting and general management. It is clear that most errors creep into the system at interfaces where humans act as "information transducers". To minimize this problem, it is essential that computers must learn to "talk" directly to other computers.

Software is the core of CIM. Software will eventually incorporate the "knowledge-base" of every manufacturing (or other) business. Yet the software "architecture" must be flexible enough to accommodate growth and change. Evidently, designing the basic system is a formidable task, which cannot (except for bits and pieces) be farmed out to consultants. This software design job must be done in-house, and it must be supported strongly from the highest management level. This is a major discontinuity for businesses. Many are likely to fail, either because they try to program existing procedures without fully understanding them, or because they wait too long to begin the necessary learning process.

Other implications already mentioned in passing: less importance for economies of scale; cheap labor is declining as a factor in competitiveness; less concentration and specialization of manufacturing in particular regions - hence less long-distance trade in manufactured goods (with some obvious exceptions). The product life cycle is getting shorter, as competitive advantage increasingly is based on responsiveness to the market, i.e., getting new products out fast. Short turnaround times means that imitation is getting easier. Patents on products are less effective, hence less important. (Patent counting is thus less reliable as a proxy for technological change). Only manufacturing competence itself offers real protection - because it is hard to imitate.

Broader implications can also be mentioned briefly. The decline of direct labor also means a decline in employment in manufacturing. This translates into higher labor productivity (although as a measure, labor productivity is becoming less and less meaningful). Product quality is increasing. Consumers will benefit also from lower prices, but the classical growth mechanism (mentioned earlier) may not work so well. Is there an alternative?

The growth industry of the future is clearly software. So-called "fixed" capital increasingly consists of specialized software. As the span-of-control by computers gradually extends from the machine level to the factory (or firm) level, the software requirement grows disproportionately.

Table 4. Software fraction or investment in moves to CIM.

Software fraction of total investment	Span of computer control	Added to prior level
0.02	Standalone machine	Instructions for machine control
0.03	Machining center	Instructions for changings tools
0.04	Machining cell	Multiple machine control
0.06	FMS(1)	Scheduling
0.10	FMS(2)	Loading/unloading, storage
0.15	FMS(3)	Inspection, sorting
0.20	Automated production line	Assembly, palletizing, kitting
0.40	Automated factory (1)	Computerization of functional modules, viz. MIS, MRP, CAD, CAPP, CAM
0.50	Automated factory (2)	Linkage of MIS, MRP, order processing, scheduling, cost analysis
0.70	Automated factory (3)	Linkage of CAD, CAE, CAPP & CAM

There is a good deal of new work for national accounts statisticians and economists implicit in this last picture. Particularly in the light of the rising percentage of costs shown in *Figure 18.*

Implications for Less Developed Countries

Finally, the situation of the LDCs deserves special consideration. We don't have all the answers. Only some of the questions. There are disturbing implications in what I have said up to this point. One is that low cost labor is no longer an important factor in competitiveness. Yet it is the only advantage offered by most LDCs. Moreover, the increasing demand for product quality works against labor-intensive methods. By this line of argument, CIM has to be viewed as a major threat to LDCs, at least insofar as they hope to export manufactured goods to the industrialized world. Indeed, it is no less a threat to the former socialist "East Bloc" countries. On the other hand, if CIM can be "home grown" it offers a possible way of supplying local needs (including capital goods) without importing them from countries far away.

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Appendix

Table A. Industrial robot population.

	Japan	USA	UK	FRG	France	Italy
1974	1000	1200	50	130	30	90
1975	1400	1549.2	58.5	209.1	49.1	121.6
1976	3600	2000	68.4	336.3	80.5	164.3
1977	4900	2236.1	80	541	131.9	222.0
1978	6500	2500	125	716.2	216.1	300
1979	9100	2915.5	215.3	948.0	354.0	369.1
1980	14250	3400	371	1255	580	454
1981	21000	4700	713	2300	790	691
1982	31857	6250	1152	3500	1385	1143
1983	46757	9387	1753	4800	1920	1850
1984	67300	14550	2623	6600	2750	2585
1985	93000	20000	3017	8800		

Source: Tani, vol 3, chapt 6, page 3.

Table B. Diffusion of CAD systems in use.

	Japan	USA	UK	FRG	France	Italy	USSR
1976	160						
1977	150					120	
1978	320					170	
1979	730	7150				260	
1980	1120	9900		400		410	
1981	1530	14000	1660	1230		580	
1982	2900	35800	4000	1500	2250	800	
1983	5300	44100	10000	11000	10000	890	
1984	9100	54400	13000	16000	12000	1000	
1985	10400	132200	17000	21000	14000	1500	770
1986		210000	23000	26000	16000		1000
1987			31000				2300
1988			56000				

Source: Astebro, vol 3, chapt 7, page 6.

Table C. Diffusion of NC machines in use.

	Japan	USA	UK	FRG	France	Italy	USSR
1980							21600
1981	26725						28744
1982	41040.9						36558
1983	63025.5	103308					45180
1984	96786.7	122865.2					54764
1985	148633	146124.7	47200	67500			65488
1986		173787.5					77389
1987		206687.1					88550
1988		245814.9					99495
1989		292350					

Source: 1985 OECD dic 1989 page 118, USA: American Machinist
USSR: Our calculation on vol. 3, chap. 4 page 3.

Table D. Diffusion of FMS.

	Japan	USA	UK	FRG	France	Italy	USSR
1976	39	12	0	2	1	0	7
1977	45	12	0	4	1	0	7
1978	55	16	0	4	1	0	8
1979	71	24	0	10	2	1	10
1980	84	31	0	18	3	2	12
1981	102	41	2	24	6	5	13
1982	132	53	9	31	17	7	18
1983	165	61	16	49	24	11	23
1984	182	81	29	55	37	27	29
1985	195	101	51	67	44	31	40
1986	202	111	62	75	58	33	49
1987	212	132	86	82	65	40	53
1988	213	139	97	85	71	40	56

Source: IIASA Data Bank

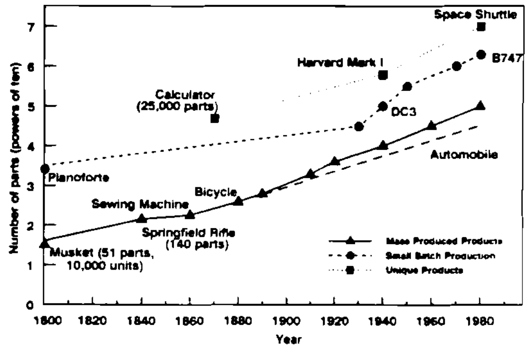


Figure 1. Complexity Trends.

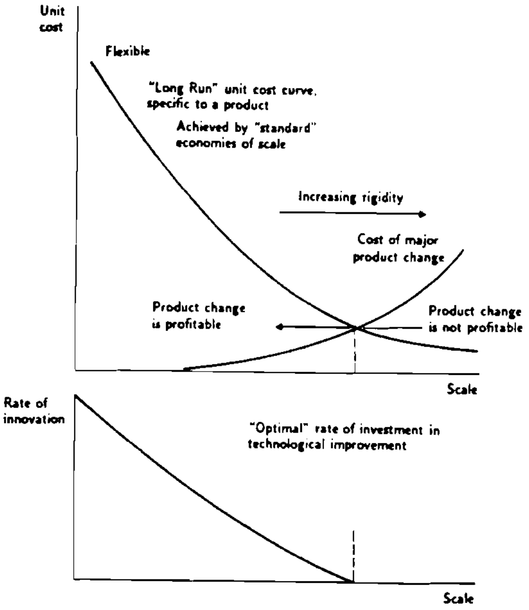


Figure 2. Productivity Dilemma. Source: Abernathy, 1978.

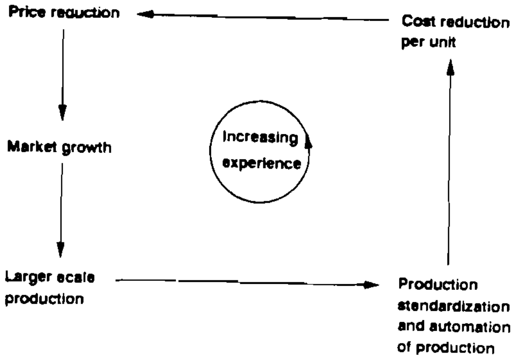


Figure 3. Cost-Price Driven Product.

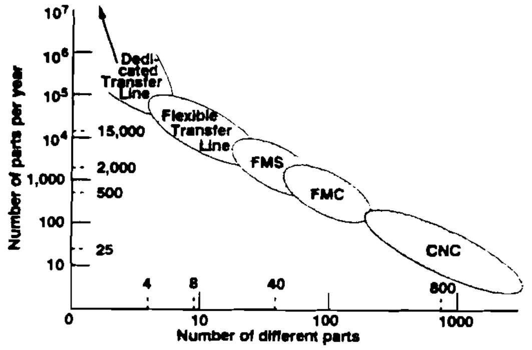


Figure 4. Volume/Variety Trade-Off.

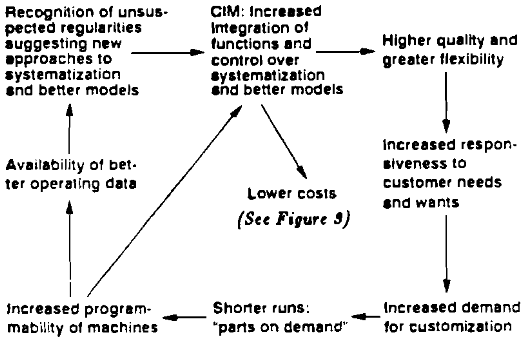


Figure 5. A New Paradigm for Economic Growth.

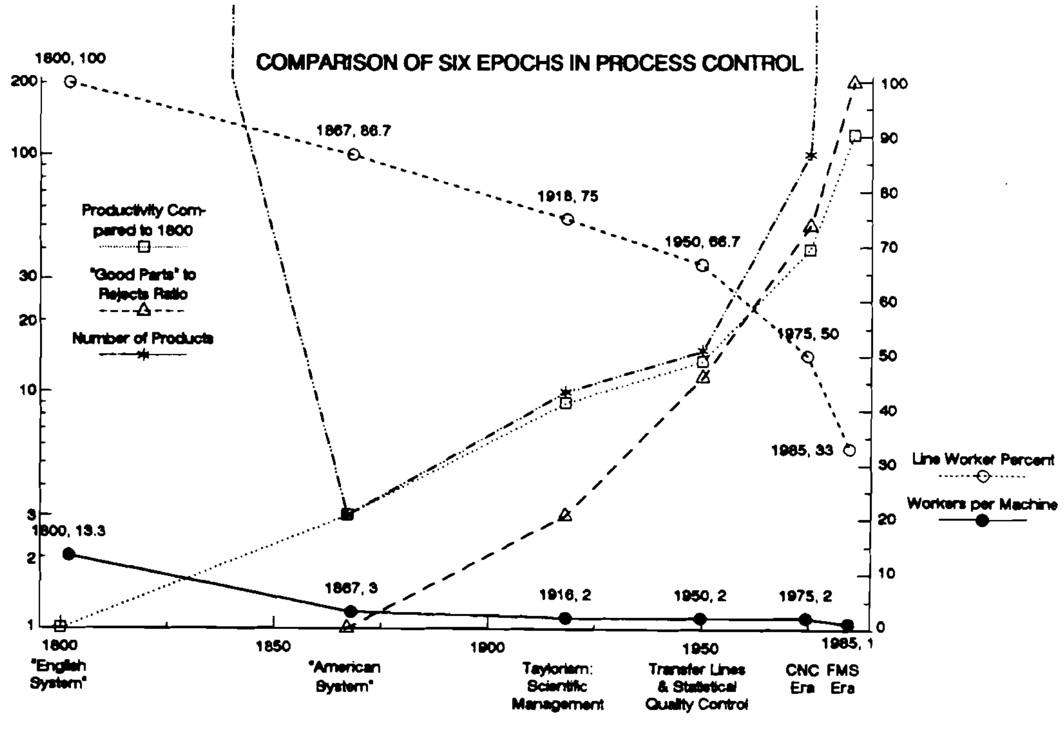


Figure 6. Six Epochs in Process Control. Source: Adapted from Jaikumar, 1989.

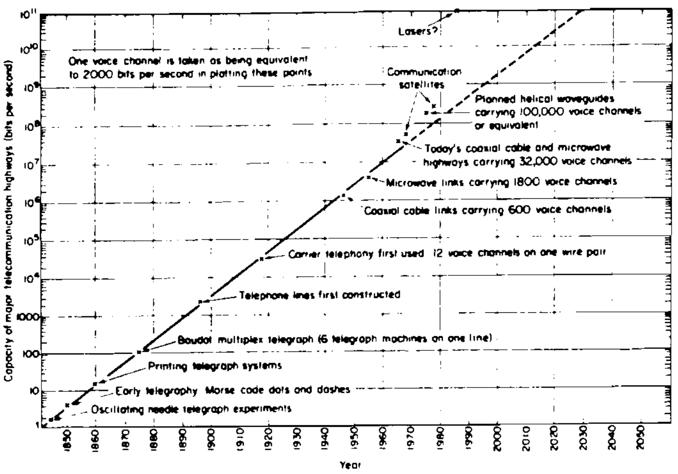


Figure 7. Sequence of Inventions in Telecommunications. Source: Martin, 1971.

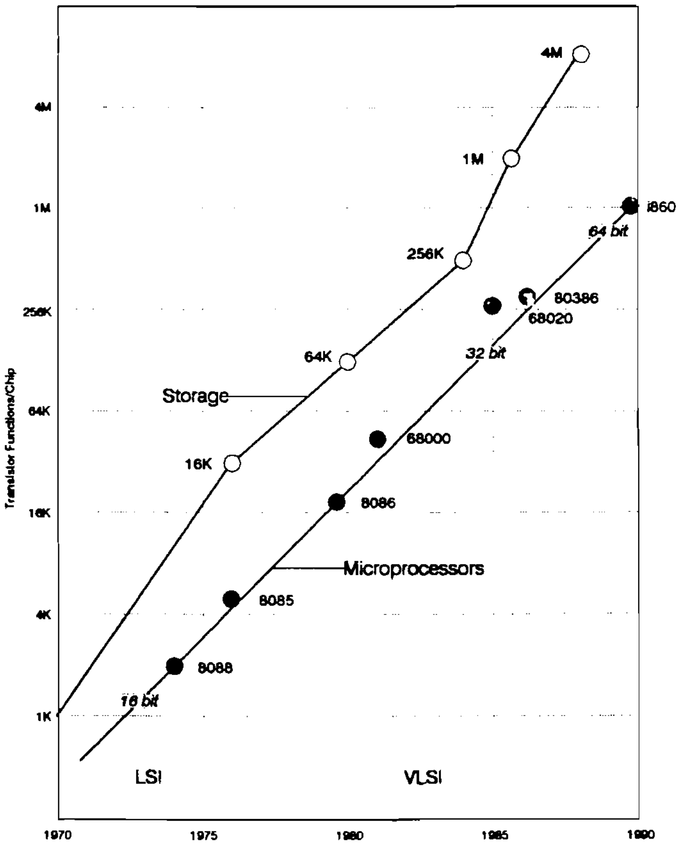


Figure 8. Development of Memory and Micro-Chips. Source: Adapted from Bursky, 1983.

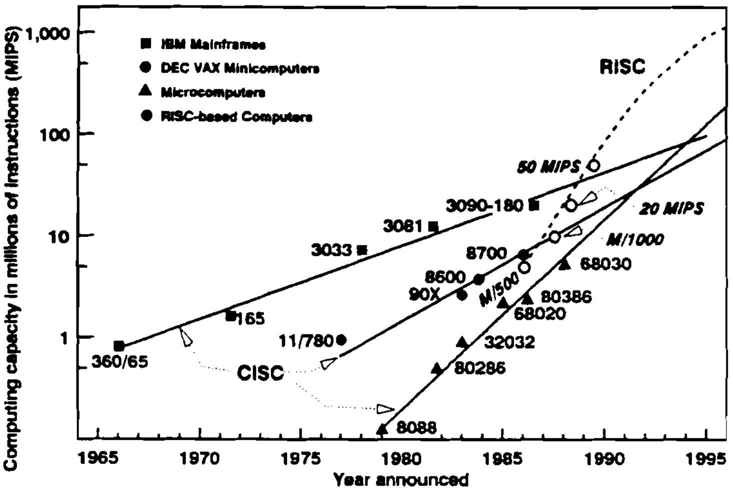


Figure 9. Efficiency of Computing Architectures. Source: Adapted from Electronic Design, 1988.

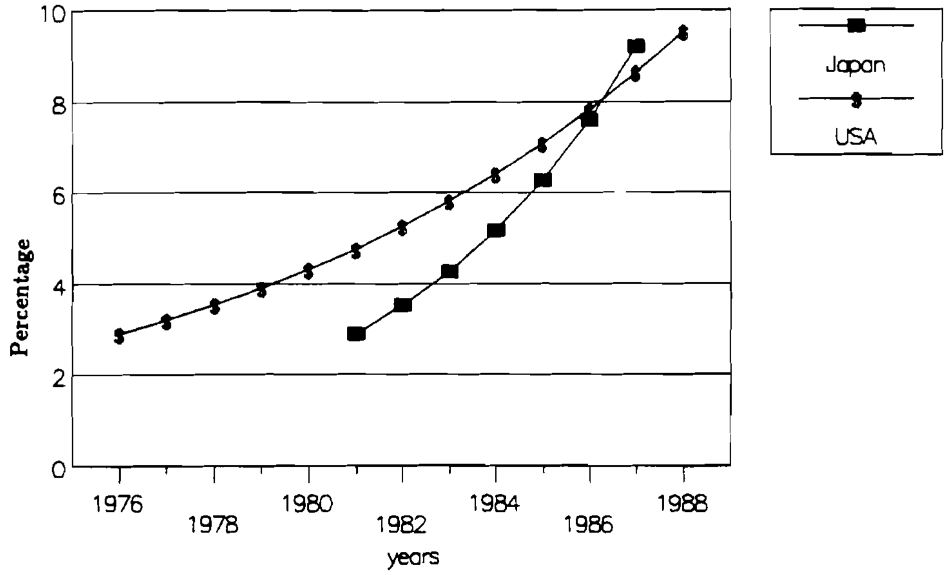


Figure 10. NC/CNC Machine Tools (% of Total).

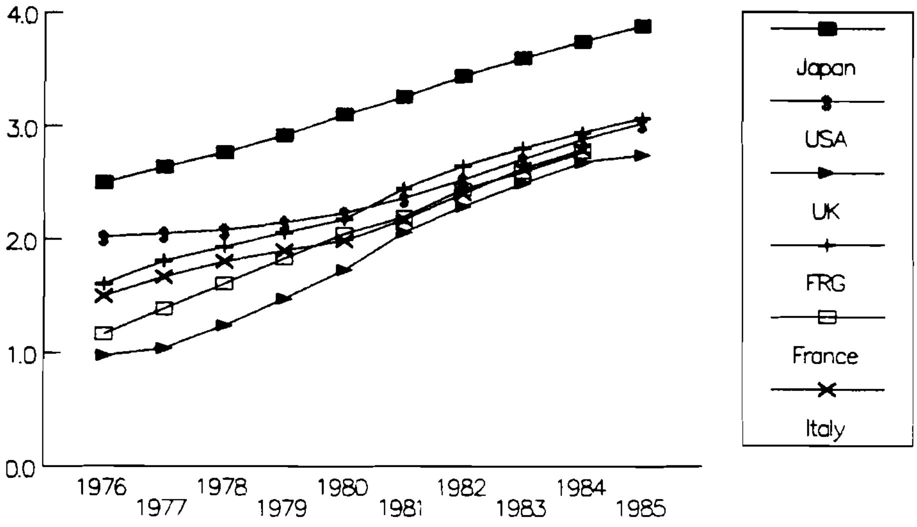


Figure 11. Industrial Robot Density. Per Million Employed (LOG Scale).

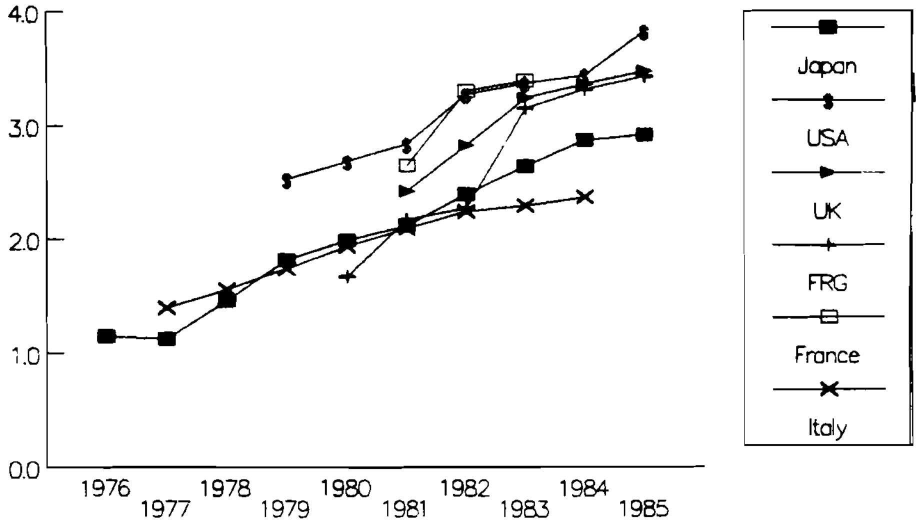


Figure 12. CAD Density. Per Million Employed (LOG Scale).

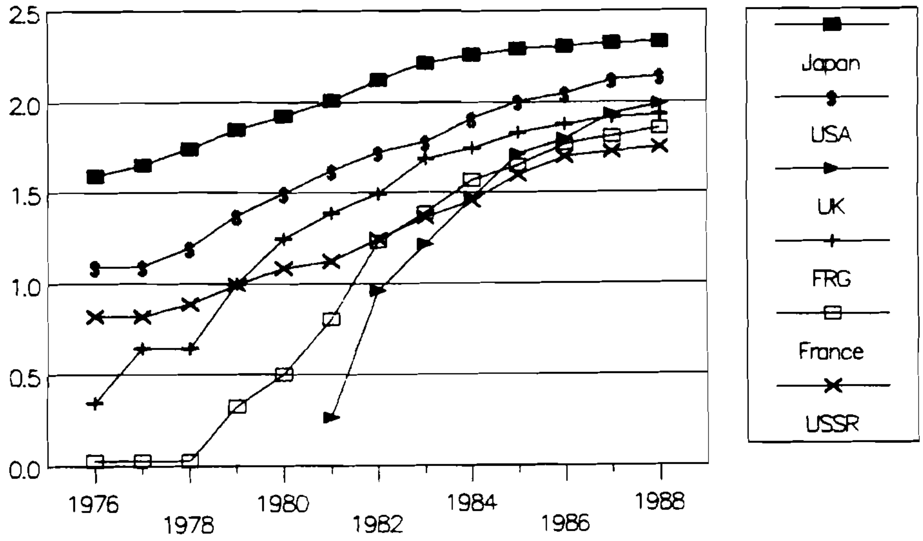


Figure 13. Diffusion of Flexible Manufacturing Systems (LOG Scale).

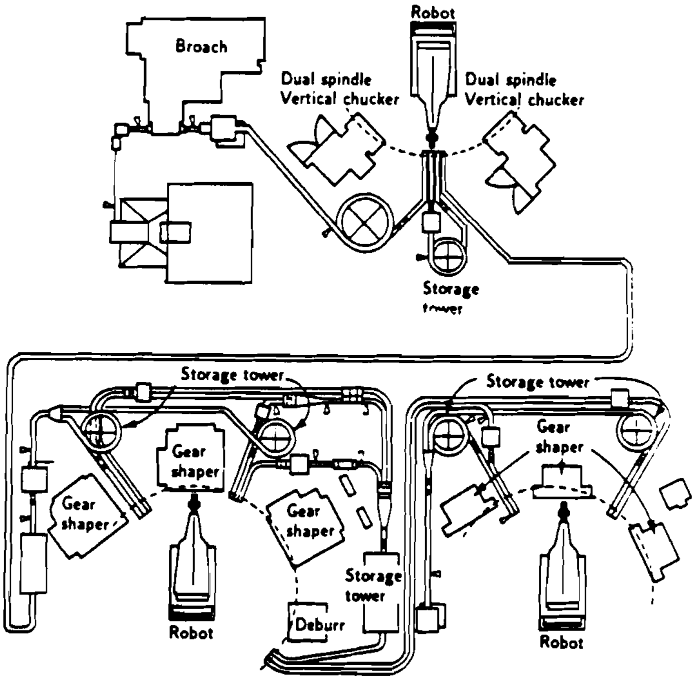
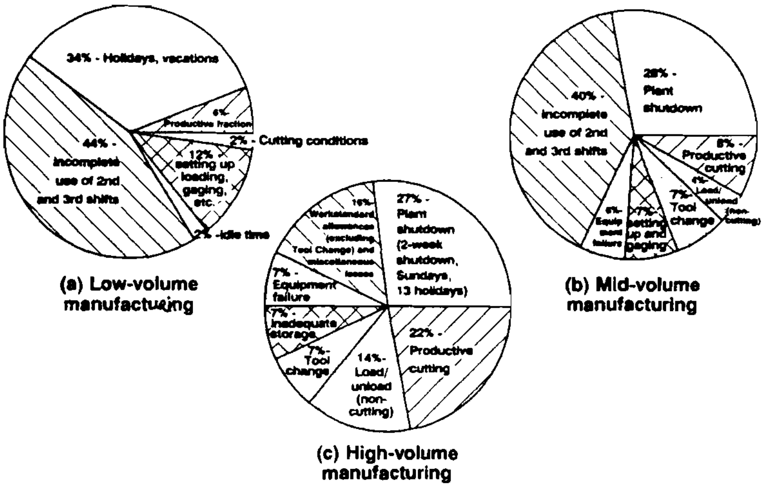


Figure 14. Flexible Automation System (Pinion Gears). Source: American Machinist, 1980.



(a) Low-volume manufacturing

(b) Mid-volume manufacturing

(c) High-volume manufacturing

Figure 15. Low/Mid/High Volume Manufacturing. Source: Adapted from American Machinist, 1980.

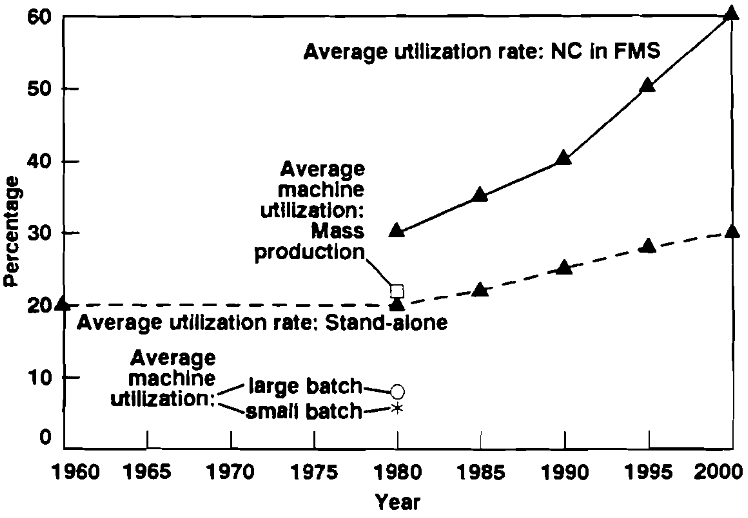


Figure 16. The Impact of Computer Control on Machine Utilisation.

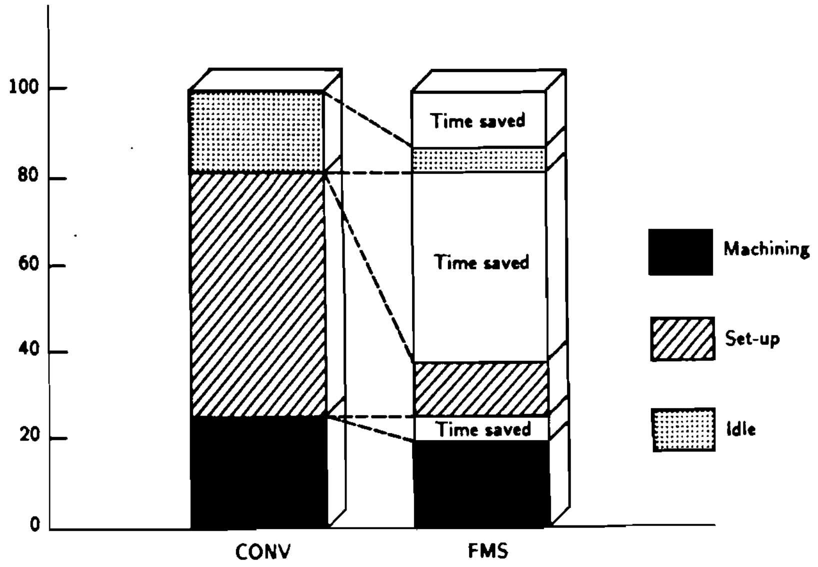


Figure 17. FMS Impact on Production Time.

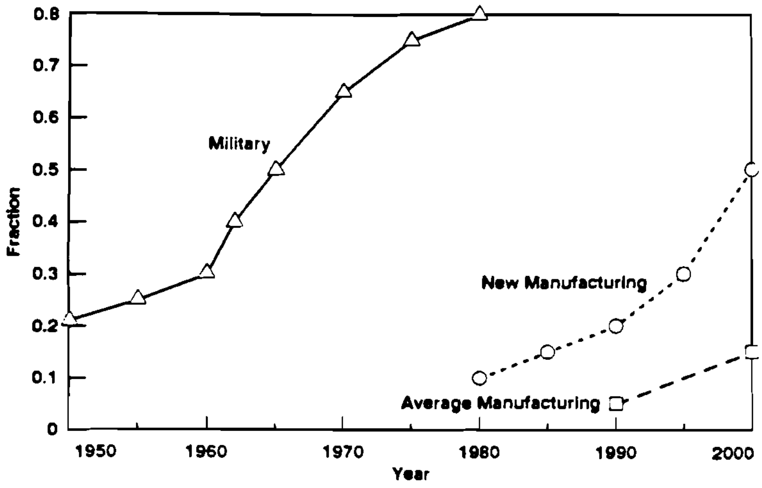


Figure 18. Software as a Fraction of Total Capital Investment.

CIM: Flexible Technologies in Manufacturing

by

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CIM: Flexible Technologies in Manufacturing

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Jukka Ranta

Introduction

The industrial robot – like the numerically controlled (NC) machine tool, before it – is often regarded as a symbol of the automated production and the structural change taking place in manufacturing, especially in the metal-product industries. This is understandable, because the robot is a visible part of manufacturing technology landscape and there are a number of mature, well established applications, like welding, painting, investment casting and surface finishing. Moreover, these (more and less) stand-alone applications were directly replacing human labor, which raised a public concern about the social impacts of robot applications. Certainly some form of robots are and were a starting point on the route toward a more automated production.

Today, however, it is definitely misleading to equate (as some analysts do) the extent of use of robots with the degree of automation. In any case, the mature stand-alone applications of robots are a harbinger rather than a corner-stone of truly modern automation. Robots *per se* are already used extensively as a part of flexible manufacturing systems (FMS) and flexible assembly systems (FAS). Beyond this there are many applications of intelligent sensors and information processing systems. These new type of applications are expanding the possibilities of the classical stand-alone applications of NC machines and robots. At the same time, impact assessment is becoming more difficult, because the benefits and costs are not simple or direct any more. In fact, the most critical part of the benefits (and part of the costs, too) is indirect and qualitative. Therefore, when assessing new manufacturing technologies one must look beyond stand-alone applications and focus more on systems applications, such as FMS/FAS.

It is quite often argued that the major source of benefits from automation comes from labor savings. Labor reduction is often cited as a goal in the applying of production automation. This was largely true in the case of the simple stand-alone applications. In the case of FMS and FAS this is not the case, however. There are complex interdependences making the assessment difficult. Also there tend to be unintended impacts. This fact leads us to argue (mainly in Volume V) that implementation issues and practice are critical factor behind success. In fact there is a lot of practical evidence derived from many case studies.[1] that implies that the most

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[1] See Ranta *et al.* (1988, 1990); Jaikumar (1986); Goldhar *et al.* (1983, 1985); Meredith (1987).

critical issues for the application of advanced production automation technologies within firms are managerial and organizational in nature.

However, in the larger context, the situation is even more difficult, because the basic manufacturing technologies are not at a mature stage of development. Thus it is reasonable to expect that future technological improvements can still contribute considerably to the technological and economic efficiency of different production technologies. We can also expect that many potential "systems" applications are simply dependent on the scale, scope, and capital intensity of different manufacturing technologies. Thus the stated goals and targets of production automation – such as flexibility, accuracy, processing speed, and complexity of parts – are really secondary. They are merely the trade-off between economic benefits and the costs of technological solutions.

One of the main technological driving forces has been the development of information technologies, i.e., semi-conductors and basic electronics, computer technologies including software development, and communication technologies. This has been fundamental both for manufactured products and the production technology of manufacturing industries. We expect that this linkage will be further intensified when the possibilities of information technologies are more fully utilized. The key "carriers" of technological change will continue to be the manufacturing equipment industries, which utilize the electronics technologies both in their products and in their production, and which have "forward" linkages with all other manufacturing industries, providing them with systems and advanced tools. The "motive" branches of industry will continue to be electronics, the computer, communications and electric machinery industries, which provide tools and means of production for the capital goods sector itself. Thus the manufacturing equipment industry has "backward" linkages with information technologies and related industries.

The Changing Environment

As noted above, the development of advanced information technologies in production has been, and will continue to be, the major technical driving forces in manufacturing change. The electronic and information technologies give new possibilities to produce variety of products in an efficient way. Modern manufacturing is beginning to approach the flexibility of the classical job shop mode of production, but on a productivity level that is far higher. Indeed, productivity in flexible systems can now compete with mass production methods. Also it seems evident that the information technologies help to produce goods of superior quality compared to the old "Taylorist" organizational principles. Yet the new production systems seem to function efficiently on a much smaller scale (in terms of machines and personnel) than the older mass and large series production systems.

Why is greater flexibility needed now? On the one hand, there has always been a demand for "customization" of products, and for special "niche" products. However, this was not cost efficient until recently because of technological constraints. So one can say that production was rigid and the customers were necessarily flexible. Due the rapid development of information technologies, it is increasingly possible to combine efficiency and flexibility in a single productive unit. The customers can start to be more inflexible about their desires and production has to be more flexible and adaptive.

Thus, it can be argued from one perspective, at least, that industrial change is now mainly technology driven. The information technologies, in particular, provide new options. These promote a continuous search for competitive advantage and for ways to "take-off" from the classical mass production into a more competitive and beneficial environment. This means that, in order to gain benefits from information technologies, companies must actively look for new options. Previously it was normal to make a single product, using specialized machinery and skills, and to market it more or less unchanged to many, global markets. Now it is necessary to make a variety of products using flexible machinery and multiskilled personnel, targetted to specific, segmented markets. *Figure 1* shows some major indicators of the change.

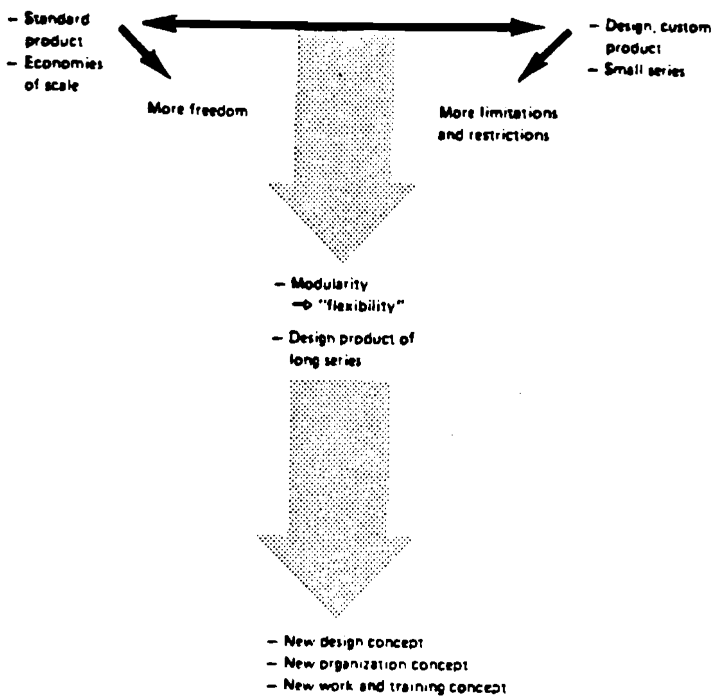

Figure 1. Flexibility and changing principles of production.

Parallel to the technology push there are also changes in the business environment. These changes also necessitate a shift to more flexible operation principles. To some extent, one can say the there is a social need for flexibility. The new production technologies (and associated management principles) are reacting with the markets in an interactive way responding to the new needs and at the same time creating new needs.

In the first place, time is becoming more important in the new environment. Due to rapid technological development (mainly in the electronics and information sectors), product life cycles have become shorter. This is especially true in consumer electronics, the automobile industry and consumer durables. (Of course, in the clothing, furnishing, and housewares industries there is also a need for continuous and rapid changes of styles and products.) Thus in general, the product renewal rate has become higher. To be efficient and competitive in this environment, manufacturing companies need flexible design and planning systems and flexible production. This is necessary to introduce new products and designs rapidly into production, and to the marketplace.

Parallel to the higher renewal rates and shorter product life cycles, total delivery time has become an important competitive factor. This is closely related to the tendency to increase customization of products and to just-in-time (JIT) production principles developed in Japan. Competition on the basis of minimizing total delivery times in turn requires short order-processing time, short throughput time in production and efficient logistics and distribution systems. To cope with these demands, information technologies are the essential ingredient. They provide flexibility in the design and customizing of products, in production planning and control, in manufacturing and also in the supervising of logistics activities. Apart from providing benefits to the customer, savings of time in all phases of production result in capital savings in the form of reduced inventories and work in progress.[2]

The second dimension in the new business environment is product variety. The tendency toward increased product variety is a result of more customizing of products and specialization of market segments. In the capital goods sector, application-specific machines and devices can be more cost efficient to the final user if the extra cost is not too great. Similarly, in consumer goods production "customizing" fulfills individual needs better. The rising income level in the Western industrialized countries is promoting the tendency toward product variety, because consumers are increasingly ready and able to pay for specialized and customized goods.

Increased product variety, in turn, requires more design intensiveness, more complex production planning and control, increasing part variety in manufacturing and more complex and difficult logistics. To cope with these problems, sophisticated information technologies are needed in planning and production to provide both efficiency and flexibility. It is worthy of remark that the customizing of products is not always a reaction to the changed competitive environment. The flexibility needed to respond can also be used in an active way to create new market options and new competitive advantages.

For practical purposes, and to understand the role of different technological and organizational options, we can define three types of flexibility from the company and enterprise point of view: ***operational, tactical*** and ***strategic.*** Operational flexibility is needed to cope with existing product variety in an efficient way. The basic objective is to produce different products from the existing (already designed) product family, in a random order, in different batch sizes, and with different and varying delivery times.

Tactical flexibility is needed to cope with the accelerated product renewal rate and to respond more quickly to changing markets. This means shorter turnaround times. The objective is to change or to increase the existing product family without making expensive changes in the technology of production. Both the design and planning system as well as the manufacturing system have to be flexible. To some extent, tactical is an outgrowth of operational flexibility.

Strategic flexibility is the ability to cope with major changes in the environment. Usually this means responding to evolving market needs by introducing new products, developing new product features or changing the technology of production of the company. It can also be an active searching for new options and new advantages. To exploit fully the possibilities of strategic flexibility, a company needs not only specific technological capabilities, but the whole management structure of the company has to be flexible. Therefore organizational innovations and new collaborative forms are important.

It is also important to note that this concept of flexibility implies a hierarchical relationship. A high level of operational flexibility makes it easier to create and extend tactical flexibility and also it is difficult to have tactical flexibility without having operational flexibility. The same is true for the strategic flexibility: to provide strategic flexibility a company needs both operational and tactical flexibility.

To achieve the different types of flexibility a company needs a range of organizational and technological tools. ***Figure 2*** presents the role of different functional systems in terms of providing flexibility, especially in the time dimension.

The cornerstone of operational flexibility in manufacturing today is the so-called flexible manufacturing system (FMS). However, it is not sufficient. In terms of time saving, the design, planning, and logistic information systems are more critical and often more benefits can be extracted from these auxiliary systems.

In the case of tactical flexibility, to cope with the high renewal rate of products, the design, planning and logistic systems are usually the starting point and the most critical technical elements. Nevertheless, to manage product changes in an efficient way, a flexible manufacturing technology is needed.

To achieve the strategic flexibility it is also necessary (among other things) to build up a flexible subcontracting and collaborative network. This is needed to react rapidly to completely

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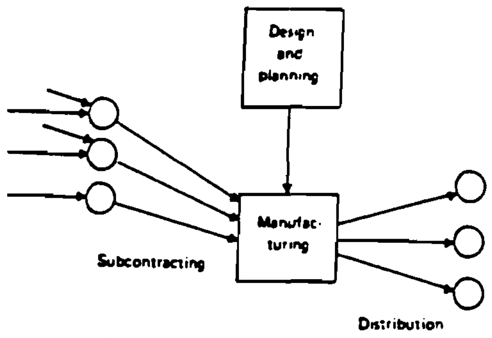
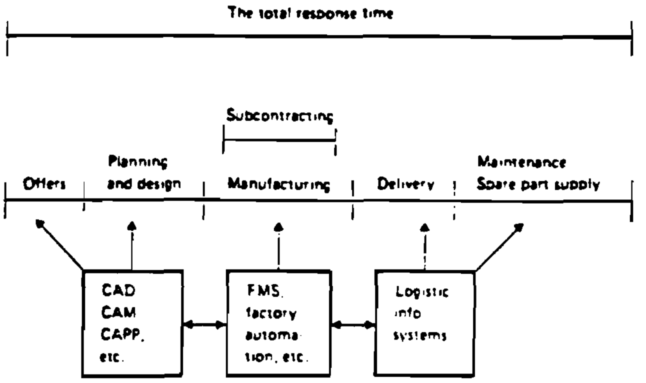
[2] See Krafcik (1988), de Vaan (1989), Stalk (1988).



(a) Network organization



(b) Functions and CIM systems

Figure 2. Organization, functions, and CIM.

new demands. Then the logistics system plays a critical role.

Apart from technological means, new organizational solutions are also needed. These are needed to cope with the increasing integration of the production systems, to guarantee high utilization rate of the systems, to cope with quality requirements and to cope with continuous changes in general.

Now we can see what Computer Integrated Manufacturing (CIM) means in practice. It is a method or approach to integrate different functions from market planning, product design, production planning and control, to manufacturing and distribution, by means of computers and information technologies. It is clear that, in practice, there will be and must be different approaches toward the implementation of the CIM-technologies, depending on the circumstances. Indeed, the goals and intended benefits, as well as realized benefits, are different in different business environments.

Figure 3 illustrates the situation. Instead of the classical volume – product variety axes, the product renewal rate – product variety axes are used as key variables. The production volume or capacity is expressed as isocapacity curves – *isoquants* – in the figure. It appears that there are different areas and environments for an economic use of flexible manufacturing systems. It

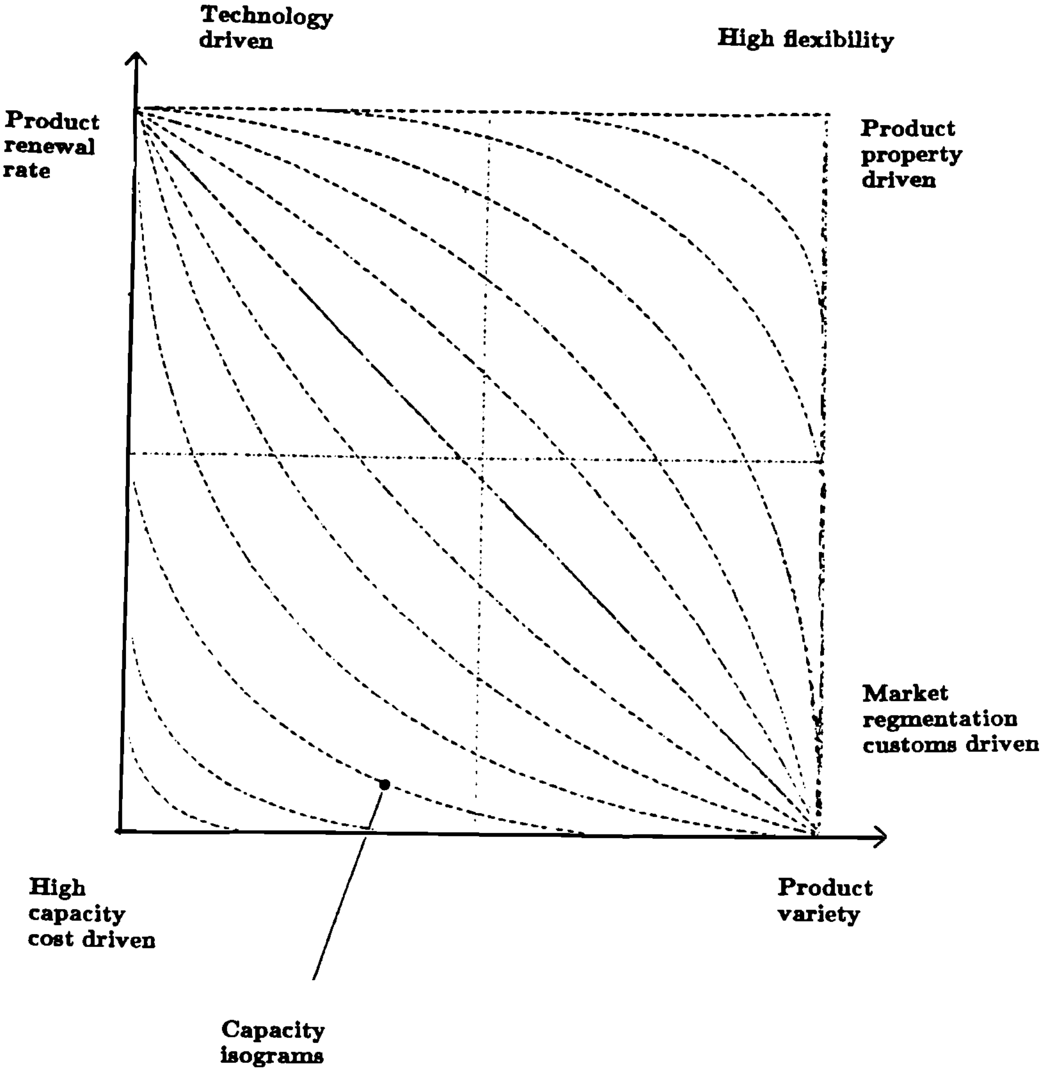


Figure 3. The interaction of capacity, product renewal rate and product variety.

follows that the strategy toward CIM implementation may be different in different environments. The four corners correspond to four different idealized cases.

The "high capacity" (lower left) corner corresponds to a situation where an efficient and cost effective manufacturing system is an essential starting point. In practice this still means specialized and fixed systems, such as transfer lines.

In the left upper corner, a high product renewal rate is a characteristic feature of the business environment. We can say that this environment is essentially "technology driven". To cope with changing product mix, sophisticated design and planning systems are needed as well as a flexible manufacturing. This is an environment where robots, FMSs and FASs are likely to be found.

The lower right corner is characterized by customized products and special market niches. An essential starting point is sophisticated design, planning, and logistic systems. Flexible manufacturing systems may be used to cope with increasing market demand resulting in a need to expand capacity.

The right upper corner is likely to be the area of a semiproduct or subassembly vendor or supplier. There can be many and rapidly changing products in production. Here, too, sophisticated design, planning and logistic systems are essential and FMSs may be needed to cope with the need to increase capacity.

Evidently the goals for production automation are not simple. In practice, today, manufacturing automation is applied in a multicriteria environment. Automation systems are not only used to reduce direct labor costs, but to cope with a changing business environment and to create new competitive advantages and options.

Production Automation – The Systems View

No attempt will be made to give a complete definition of computer integrated manufacturing (CIM) in general. In the previous section CIM was defined as a process toward the integration of different systems. An illustration may be more helpful. It is presented in *Table 1.* Accordingly, CIM integrates different technologies as well as different fields of engineering and knowledge.

Table 1. Levels of production automation.

	Technology base	Essential knowledge base
Planning methods	Applications in different industries	Customized needs, application know-how, project management methods, organization design, impact analysis
Production planning and control CAD/CAM CAPP	Planning and engineering Project deliveries	
	Systems Flexible manufacturing units (FMU), flexible manufacturing cells (FMC) and systems (FMS) Factory automation Software systems Production control systems	System engineering Manufacturing engineering Software and computer technology Information technology in general (especially communication)
	Machine automation NC, robots, automatic storages, automatic vehicles, etc. Special production machines	Mechanical engineering Electronics and software technology “Mechatronics” Control engineering
	Production interfaces Sensors, transmitters, servomechanisms, switching devices, etc. Special devices	Physics Mechanical engineering Electronics Special methods: signal processing, pattern recognition, image processing

We can differentiate four basic levels. The heart of production is, of course, the machine level. Machine tools were the starting point of manufacturing automation (see Chapter 3) and the machine tool manufacturers were early users of electronics and information technologies in manufacturing. Modern machines have two kinds of interfaces. The first is an “inward” interface with the workpiece and other machine elements. The interface consists of sensors, transmitting devices, servomechanisms and switching devices. A modern NC-tool or robot can have its own microprocessor control for each axis of the motion, custom-designed semiconductors in servomechanisms, as well as sensing and information processing devices. These are real “mechatronic” products, combining mechanical engineering, electrical engineering and electronics.

The second is an “outward” interface with the systems level and the planning process with different communication systems. The systems level is the second level, integrating single machines with the help of computers and communication technology and material handling and transportation devices. There are flexible cells (FMC), combinations of cells in the form of flexible manufacturing systems (FMS), or even a combination of several FMS in a factory-scale system. For such an integration, systems or single machines have to be able exchange data and information. Therefore a combination of communication technology with computer technology is important– not only for the integration, but also for the upward interfaces to different planning systems. Another crucial issue is the mechanical integration of machines with materials handling devices and storage systems. In general, manufacturing systems are still at an emerging stage; there are few (if any) standard modules for the software and the communication components of the system. Thus, software engineering is one of the key issues on the machine systems level.

There is also a third level consists of different planning and design systems. These include CAD, CAM and process planning (CAPP), as well as production planning and control. The planning level has been the second starting point for information technology applications in manufacturing and it has been far ahead of the systems level. In particular, CAD and production control systems (e.g., MRP) are well established and intensive users of computers. However, there have been problems with the integration of different planning and control technologies, such as CAD, CAM and CAPP. Ideally, it should be possible to generate the required tooling steps, routing instructions and NC-controls, directly from the design data bases. The same is true for the interfaces with the manufacturing systems level and the logistics systems. Thus, software engineering and communication technology are critical factors in the integration of design and planning with manufacturing and logistic systems.

The fourth level, which is emerging parallel to the manufacturing systems, comprises application design and related engineering and project delivery activities. This can be regarded as a separate level or business activity, because there is a special need to reconcile customization requirements and technological possibilities and to specify applications as well as the systems architecture. The growing need for these activities is partly attributable to the lack of common systems solutions and the novelty of systems technologies for small and medium-scale industries (see also Bullinger, 1985; Kelley *et al.*, 1988).

Apart from this vertical classification, CIM technologies may also be classified horizontally according to the required processing steps. For instance, there exist different technologies for sheet metal processing, part tooling for prismatic and rotational parts and product assembly. To achieve overall integration, different tooling and manufacturing steps must be incorporated in addition to different functions.

The essential point is that there is no single, well-defined production automation technology. Flexible manufacturing technology combines many different devices, machines, and systems. It is also clear that software engineering plays a major role at the systems level. Moreover, organizational and marketing innovations (understanding special needs) are the key factors in a successful applications.

This integrated systems aspect of production automation makes it difficult to define "a life-cycle model" for flexible manufacturing automation. The systems concept (CIM or FMS) is still at the emerging and developmental state, but it can utilize mature technologies as components. Yet radical innovations (such as laser cutting) will play a major role in the future as they become technically feasible and economically competitive.

FMS can be considered as products and as product innovations. However, major difficulties arise for many industrial branches when FMS (and CIM) systems are regarded as production innovations. In practice, the successful application of FMS or CIM requires major organizational adaptations. FMS and CIM are always special, customized systems. There are no unified, standard FMS or CIM technologies. For this reason application know-how (marketing innovation) is essential in the systems planning and the project output, see (Ranta 1988).

The integrating as well as the emerging nature of the FMS and CIM concept also reflects the fact that, as business activities, FMS and CIM are very diversified. There are specialized vendors for NC-machines, robots, AGVs, sensors, microprocessors, MRP software and so on. In addition, there is a newly emerging line of business: systems integration and systems engineering, which is software-oriented, but which requires a thorough knowledge of a certain application area.

Finally it should be noted that each industrial branch (metal products, electronics, clothing) requires its own special application knowledge which, in general, is not transferable from one branch to another.

Backward and Forward Linkages

In order to forecast the future applications and diffusion of technology, it is essential to know the routes of diffusion. These routes may be called forward and backward linkages. *Figure 4* illustrates the basic way of thinking. The forward linkages present practical needs or "market pull". The backward linkages can be regarded as "technological push".

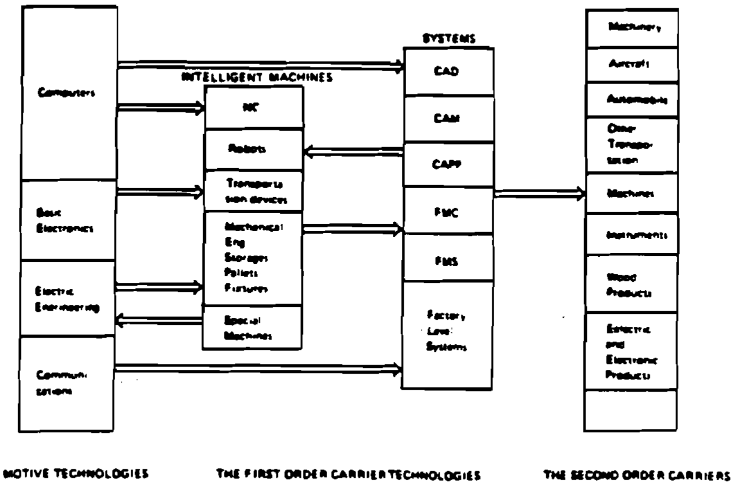


Figure 4. Motive and carrier technologies.

It is useful to identify the carriers of technology. The first-order carrier branches consist of the machine-tool industry, the robot industry, and related industries. The development of these branches has been heavily influences by information technologies. They also provide the components for systems integration. The latter is mainly based on extensive applications of sensors, microprocessors, computers and communication technologies. Important special issues include distributed processing and databases as well as local area networks (LANs). Thus software engineering also plays a crucial role in this context. On the machine level the driving forces are, apart from computer technologies, the integration of mechanical engineering and electronics, and even of the basic component technologies, into the machine design. Electrical equipment plays a special role, notably in the area of servos and motor drives.

The main application areas can be called the second-order carrier branches. These are, apart from the machine-tool industry itself, the main users of the basic machine-related technologies. So far, the main branches have been general machinery, the automobile and other transportation equipment industry, as well as the electronic and electrical machinery industry. These branches will also be the main users of flexible manufacturing technology in the future. Depending on technological capabilities and economic efficiency, one can expect the diffusion of flexible manufacturing technology to extend eventually to small and medium-scale enterprises as well as to marginal branches like plastic and wood products.

There are some special branches, like the clothing industry and printing, which are extensive users of information technologies. But they are somewhat outside the mainstream of the development, because they involve special materials and specialized machinery.

With regard to the backward linkages it is safe to assert that the manufacturing industries will *not* be the key industries influencing the future trends of semiconductor and computer industries. In Japan and Europe this influence can, to some extent, exist. But in general we can regard semiconductor and computer technology (from the manufacturing viewpoint) as an autonomous force. It will evolve, in the near future, according to its own laws, or it will be driven by aero-space, telecommunications and military requirements. In effect, the backward linkages generate a real technological push.

As mentioned before, the engine of change in manufacturing is the machine-tool and the related manufacturing systems industry. This sector has provided the basic components for systems integration. It was also the first *user* of FMS in its own production. In that way the machinery sector has been the key to systems integration in more ways than one. It has been evolving from a component supplier and a systems applier to a systems vendor. A second path to systems integration has been through electrical components and controls. Historically, this industry has provided special components and controls to the machine-tool industry. It has also been an early user of the systems in its own production. It is quite a logical step to move from systems control to systems integration and related software products. The third main path has been from the computer and software industry to manufacturing software integration. This is, at present, the most dynamic group. Systems and related software products are still mainly customized, due to a lack of common standards. So far there is no common control structure, either for systems, or for their architectures.

It has been, and still is, common that systems integration is carried out as an in-house activity directly by the final user of the systems in the application area. This is to a great extent due the customizing of systems. At the present time there is also a common phenomenon that systems are supplied by a consortium of companies, which can be even international. Such forms of cooperation usually consist of a systems integrator and several component suppliers, where the systems integrator has the main responsibility. Such consortia seem to be sustainable forms of collaboration.

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2. STRATEGIES AND MODELS FOR CIM

The Anatomy of Strategic Thinking in CIM Development

by

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Abstract

CIM development depends heavily on priorities which experts – policy makers and designers – use in their strategic choices among alternative courses of actions. Knowledge about such priorities, if properly acquired, could serve to help in the accurate prediction of future CIM technology performance, and it's social and economic implications. This paper describes the concept of strata scenario as a constructive way to accumulate knowledge for real choices and all their attendant priorities. Modeling such a strata scenario is achieved with the help of a hybrid expert system. The strata scenario analysis was applied to an FMS data base containing more than 600 projects in 11 countries. The results of the analysis reveal major interrelations which exist between certain strategic choices and success/failure properties of the currently developing FMS-CIM technology.

Introduction

Flexible manufacturing, as a tendency in modern industrial production, creates complex socio-technological concerning technology, as well as the people involved in or influenced by such technology. Any strategy intended to develop and promote flexible manufacturing faces the need to take risky choices concerning uncertain economic and social implications. In order to reduce such problems it is possible to employ professional knowledge and experience collected by practitioners and experts in the field. Modern intelligent techniques, such as expert systems, knowledge bases, decision support systems provide valuable tool to handle that knowledge-based information.

This paper deals with the problem of intelligent, knowledge-based computer modeling of CIM development. It also presents a concept of strata scenario analysis which contains a core idea for extracting indirect (usually implicit knowledge) about dominant reasons, motivations and preferences existing in strategic choices of the alternative approaches aimed at advancing flexible manufacturing. Here we assume, given the fair preconditions, that similar priorities in the choices lead to sufficiently similar outcomes of the corresponding solutions. However, the individual right of a decision-maker to share such data, as well as the difficulty in objectively stating preferences, is a restriction to the direct analysis. With the help of intelligent techniques, it is worthwhile to try to find another way to clarify original priorities by identifying them through backtracking, that is through analysis of the similarity of the known or proven outcomes. Such an approach has been developed and implemented within the scope of a hybrid expert system.

Strategic Choices and Scenario

In formal definitions of a scenario we follow the terminology offered by Dubov *et al.* (1986) for dynamic decision-making problems . Accordingly, the CIM development scenario is based on a time-dependent sequence of strategic choices among alternative CIM design patterns which are aimed, given a definite time period, to meet certain demands on industrial products. Here the term "industrial products" is used in the broad sense, so that it widely embraces separate parts or component materials as well as the whole complex production technologies.

Let X(t0) be the initial set of alternative CIM design patterns; T = {t0,t1,...,tk} – the sequence of discrete-time moments at which choices x(tk) are made; f(x(tk)) – the vector estimation of the alternative x(tk). Then strategy (scenario) x(T) is the composition of the strategic choices:

$$\{x(T)\} = \{x(t0),x(t1),...,x(tk)\}.$$

At tk = t0 the strategic choice x(t0) is made from the set X(t0), that is $x(t0) \epsilon X(t0)$. If tk = t0, then strategic choices essentially depend on the time variable and preceding choices:

$x(tk) \epsilon X(tk,x(t0),...,x(tk\text{-}1))$.

The vector estimate function $f(x(tk))$ consists of $n=1,N$ attributes:

$f(x(tk)) = \{f1[x(tk),tk,x(t0),...,x(tk\text{-}1)],...,fn[x(tk), tk,x(t0),...,x(tk\text{-}1)]\}$.

Clearly, any particular total vector estimate has to be determined in accordance with the selected rule of the attribute aggregation. For instance, in the simplest case of complete independence of the alternatives set and estimations on time and preceding choices, the total vector estimate of the strategy $\{x(T)\}$ will be as follows:

$Fi(\{x(T)\}) = \sum_k fi(x(tk)), i=1,...,n; k=0,...,K$.

As to the real-world problems, the situation is quite different, and such estimations may have dependence not only on previous steps but also on the ways' used to gather the alternatives together. All these dependencies, added to the variety of attribute compositions, show strong impacts on choices, and set up a firm basis to study them as important part of the scenario-related knowledge.

The Concept of Strata Scenario

The above definition of scenario analysis obviously underlines that any kind of a strategy directed to innovate or reconstruct the existing manufacturing practice and policy, is initiated and governed by such a key factor as a change in product demand. Therefore, the basic knowledge for strategy modeling could be obtained through comprehension of the process by which the demand change is evolved.

In a simplified form, the demand generation loop is shown in *Figure 1*. In general, the main sources of the demand change are two-fold: market demand data, and predictions on the demand changes. At this point it is essential to note that all these sources, market demand as well as predictions, have intensive applications in both, market and planned economies. But the deep-rooted structural differences in the management mechanisms give preference to market demand in market economies and to predictions of demand changes in planned economies. The second way, for the USSR and some other countries, has proved to have many disadvantages. This is why changes in the USSR economy are aimed, among other targets, to a optimal combining of market demands and predictions.

After demands are obtained, the next logical question is "how to meet the demand"? This depends on a particular manufacturing potential which calls for alternative strategies to embody the potential.

There are a number of special features - in view of such a demand generation loop - which do not allow the use of straightforward scenario building.

(a) An industrial product might imply goods and means of production as well. The demand for goods can, but not necessarily, lead to additional demands for production equipment including the need to add raw materials, energy, investments.

(b) Originally demands arise for finished products and, in order to interpret the demand structure, there is a need to distribute such general demand into the component demands which could place the responses on different industrial sectors or enterprises.

(c) Usually demand predictions are expressed in monetary terms, although manufacturing deals with the product flows expressed in natural terms. Transfer from monetary to natural terms might cause problems.

(d) As a rule product demand has a country-wide, sometimes even global importance, but the response in meeting such demand is of interest to a limited strata, such as certain technology or production formations scaled by output performance, batch-sizes, production volumes.

Given that demand is determined some way, we can differentiate at least, between two types of scenarios – local and general/global ones. The local scenario is the strategy built on the premise that the demand for a particular kind of, say, a mechanical part, is completely known. Perhaps, only in this case is a simple straightforward strategy possible.

The general/global scenario is the strategy provided in response to the integral demand for a compound type of product, such as finished goods or new manufacturing technologies. It is quite clear, bearing in mind such a compound product, that different components of the product could require different approaches and strategies for their development. Thus, being a compound strategy, the general/global scenario has to absorb and correlate several distinctive strata profiles such as a specific technology profile, type of production profile, scale of production profile, industry, region or country profile, etc. All this strata profile data, collected and processed thoroughly, provides a valuable basic knowledge to help in making strategic choices.

We shall call the strategy, which reflects certain strata profile data, as the strata scenario. The more profiles and strata scenarios are gathered together under the common data base, the better and deeper knowledge is acquired with respect to decomposed strategic decisions. This creates some kind of intermediate or partial knowledge which can easily be drawn together and composed within the scope of local or general/global scenarios.

The Model of a Strategic Decision

In accordance with these consideration a strategic decision x(tk) is a single act of choice among alternative CIM patterns X(tk, x(t0),....,x(tk-1)) which is performed on the basis of the vector estimation f(x(tk). A decision maker displays his preferences through the way he combines the attributes f1,...,fn of the vector f(x(tk)) and gives them a ranking as well. The CIM patterns are actually described by almost canonical set of attributes representing technological, economic and social dimensions. However, shifting the preferences towards some of these attributes changes strategic choices significantly.

To model the real choices, the pattern set X is the data base collection of the FMS cases implemented in different countries. Such a data base provides information on the real outcomes – the values of the attributes {f1,...,fn} – occurring due to particular choices, but there is no indication of how these attributes interact and impact upon the choices. The latter, the knowledge-based information on attributes priorities, is identified and gathered through the intelligent search process within the knowledge base of a hybrid expert system (see *Figure 2*). The most important part of the knowledge base is the strata profile -related knowledge which is being received by selectively fixing certain pairs of the attributes {f1,...,fn} and dividing the whole set X into informative strata subsets, respectively.

The expert system allows two modes of strategic reasoning -forward search and backtracking.

The forward search, based on morphological analysis developed by Iakimets (1981), is used to find logic mapping from the selected attribute compositions to corresponding clusters of the FMS cases. By this procedure, a strategic decision can be made, having the attribute priorities are given beforehand.

The backtracking mode, based on the modified J.S.Mill's method of plausible inference (Finn *et al.*, 1983, is used to identify initially unknown attribute priorities from the clusters of strategic choices belonging to the selected strata profile.

Strata Scenario Analysis

We consider scenarios within two strata profiles: "Type of production" and "Economic rationality".

Flexibility as a distinctive feature of FMS-CIM technology raises interest in analysis of strategic decisions which are made within the framework of "Type of production" strata. Clearly, the most debated type of production suited to such technology is characterized by the minimum value in batch sizes and the maximum value in product variety. If, as a beginning, we fix these two attributes then it is possible to distinguish among types of production and select strata subsets of FMS cases in the data base, as they are shown in *Table 1*.

Economic features of CIM are of interest too, especially, in view of the high cost and complexity of the modern computer-based technology. The strata profile "Economic rationality" is shown in *Table 2*. In this case two other attributes are fixed – average investment per machine-tool and level of FMS integration.

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By fixing different attributes, many more strata profiles have been collected under this knowledge base structure including different technologies, industries, production costs, social dimensions, etc.

This analysis, being carried out with the main concern being technological development, has provided the possibility for experts – policy makers and designers – to choose 18 attributes of the canonical set (*Table 3*). Of course, this list can be extended if necessary.

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(A) The Strata Profile – "Type of Production"

1) Strata scenario: "Type of production – high flexibility"

The main objective of the strata scenario analysis is to clarify the impact-producing groups of attributes and rank them by importance.

The results of the analysis are shown in *Tables 4(a-b), 5,* and *6.* For the strata scenario "Type of Production – High Flexibility" (total 44 FMS cases), three core sets were found. A core set corresponds to tight similarity of FMS clusters. The core set 1 consists of 7 cases (4-FRG, 3-USSR) and represents the strategic choices made by the year 1981. The core set 2 includes 6 cases (Japan only) and represents the strategic choices made by the year 1983. Finally, the core set 3 consists of 4 cases (2-Japan, 2-USA) and represents choices made by the year 1985. *Table 4(a-b)* gives the division of impact-producing attributes into two groups – most important and important range, and shows the result of attributes ordering by their impacts. *Table 5* shows how this strata scenario is developing in time. In *Table 6* the core set's statistics and representative FMS cases are given.

Drawing conclusions from the analysis:

(a) Strategic decisions clearly differ in the way a decision maker selects the important attributes from the canonical set. A number of important attributes, their composition and ordering are visibly changing in the process of FMS development. For the selected strata the group of most important attributes has been extended from the single one - degree of automation – up to six attributes, including the prime one on the list – FMS control system type (see *Table 5*. As a result of the development, the degree of automation attribute has shifted down the list to fifth place.

(b) The strategic decision which corresponds to the core set 3 (shown graphically in *Figure 3*) with rather sophisticated FMS cases has added two more attributes to the most important range – type of machine-tool control systems and percentage of machining centers among machine-tools. Together with the part type attribute (mainly, prismatic parts), this could be explained by the obvious trend to enforce the computer-programmable side of FMS-CIM flexibility, and concentrate technological operations around a single working site.

(c) One would imagine that the degree of integration attribute in searching for flexibility should take highest place, but in fact this is not the case. This attribute takes last place, though still important. Such a situation reflects the practical knowledge about the fast growth of investment as well as cost, with each step directed to extend the CIM integration. Moreover, it appears that for many years ahead this attribute will be overshadowed.

(d) To have highly flexible FMS-CIM solutions, at the present level of technology, perhaps it is enough to pay most attention to all control-dependent attributes, namely the FMS control system, machine-tool control systems, degree of automation. Other important attributes, such as part type and investment, become major restrictions if a strategic decision is to be optimized. For the near future, this list of most important attributes will noticeably be extended up to 10-12 attributes. At first by quality-dependent attributes, such as quality control. Scrap removal, JIT/ MRP, and so on, will be added.

Below, there is a short summary of the five strata scenarios – two for "Type of production" and three for "Economic rationality".

2) Strata scenario: "Type of production-low flexibility/>mid output"

This is a typical case of mass-production. Two revealed core sets differ in the values of production output (middle and high, *Table 7*). Specific attributes in the important range, in addition to the control-dependent attributes, are a low degree of integration, shop-like FMS type, total number of machine-tools (2–12). Clearly, a simplified solution is the rule. If compared to the preceding scenario, not much attention is paid to attributes such as part type, sophisticated equipment, high degree of automation, firm incentive to invest.

3) Strata scenario: "Type of Production – High Flexibility/High Output".

Such a scenario, unlike the previous one, is closer to the flexible type of manufacturing strategy because it deals with considerable product variety (up to 500). However, the number of most important attributes is limited (*Table 8*). Priorities are given to large-scale production. The contrast is that even the control-dependent attributes belong to the second echelon of importance. Mostly, the success of this type of FMS depends on the supportive effects of group technology.

(B) The Strata Profile – "Economic Rationality"

1) Strata scenario: "Economic Rationality – Cheap and Simple FMS"

This is a very popular scenario when searching for a low cost one tries to use two levers – steps to simple solutions and shifts to large outputs. Despite the extended number of important attributes (up to 9–11), the most important range consists of no more than 3–4 (*Table 9*). As a rule, such scenario is the fate of those decision makers who attempt to exclude any risk in the transition towards flexible manufacturing. This is appropriate to be called a "risk-averse" scenario.

2) Strata scenario: "Economic Rationality – Expensive and Sophisticated FMS"

As the opposite to the previous one, this strategy could be called "risk-prone" scenario, since major priorities are given to the highest currently available degree of integration together with paying less emphasis to possible economic losses. Such a scenario is mainly represented by the

US defense industry-oriented cases at the end of 1980s. By this scenario sophisticated technical solutions and advanced methodology are achievable and that is reflected in the rise of the number of most important attributes up to a level of 9, as well as the important ones up to 12 (*Table 10*). Another visible feature is the relatively small scale of the systems. It is very probable, that the near future will reveal more risky strategies (with a group of important attributes of around 15–20). No doubt, the proponents will have to pay for these risks.

3) Strata scenario: "Economic Rationality – Cheap and Sophisticated FMS"

This scenario is the most interesting strategy within the economic strata and it might be named "rational" scenario. It has a reasonable (for the current level of technology) number of attributes (8), the majority of them (7) belonging to the most important range (*Table 11*). Moreover, the main attention is paid to harmonization of high-level values of control-dependent/integration attributes and those attributes which provide production quality as well service activities. Such a scenario has been preferred for modern Japanese FMS cases.

It now becomes possible to compare the scenarios under the "Economic Rationality" strata.

In order to switch from cheap, simple and low integrated systems towards expensive and highly integrated systems (*Figure 4*), it is necessary to extend the composition of the most important attributes from 3–4 up to 9, and the general number of the important attributes – up to 12 or more. In the cheap category of systems the control-dependent attributes are predominated over the quality/production services-dependent attributes. In the expensive category the latter attributes move towards the top.

In order to switch from simple and costly systems to sophisticated and economically reasonable systems (*Figure 5*) it is also necessary to extend the list of the most important attributes from 5 up to 7–8, although an excessive extension might lead to raising costs. At the same time, attempts to leave the most favorable CIM area of batch production in the use of mass-production might have dramatic effects since the conventional reduction of cost could be offset by the overhead cost due to unused or underused flexibility.

Summary

The strata scenario analysis is an application of knowledge-based expert systems to the interpretation of results as well as motivations of the real strategic choices in the FMS-CIM field. By incorporating strata profile knowledge into the analysis of CIM development, the use of available information is intensified and a better understanding of the success/failure-related policies might be achieved.

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STRATA PROFILES " TYPE OF PRODUCTION "

Table 1

	BATCH SIZE		
PRODUCT VARIETY	low 1-10	medium 10-60	high >60
high 60-5000	high flexibility 44 FMS cases	37 FMS cases	
medium 10-60	30 FMS cases	medium flexibility 22 FMS cases	8 FMS cases
low 1-10	7 FMS cases	low flexibility 24 FMS cases	

STRATA PROFILES "ECONOMIC RATIONALITY"

Table 2

	AVERAGE INVESTMENT PER MACHINE-TOOL	
DEG. OF INTEGRATION	low < $1 mln.	high > $1 mln.
low 1	cheap + simple 47 FMS cases	expensive + simple 8 FMS cases
medium 2	mid (cost+performance) 29 FMS cases	expensive + sophisticated 26 FMS cases
high 3	cheap + sophisticated 6 FMS cases	

Table 3

CANONICAL LIST OF ATTRIBUTES
1. Country
2. Industry
3. FMS type
4. Part type
5. Part size
6. Output volume
7. Total number of machine-tools
8. Percentage of machining centres
9. FMS control system
10. Machine-tool control system
11. Tool change
12. Quality control
13. Scrap removal
14. Degree of automation
15. Degree of integration
16. Investment
17. Product variety
18. Batch size

Table 4(a)

ATTRIBUTE RANKING FOR CORE SETS

STRATA SCENARIO " TYPE OF PRODUCTION - HIGH FLEXIBILITY "

	CORE SET 1 (7 FMS cases)	CORE SET 2 (6 FMS cases)	CORE SET 3 (4 FMS cases)
Impact of attributes:			
1.Deg.of automation	+0	+0	+0
2.FMS control system	+1	+0	+0
3.Part type	+2	+1	+0
4.Investment	+5	+3	+0
5.Deg. of integration	+6	+7	+1
MOST IMPORTANT ATTRIBUTES:	1.Deg.of automat.	1.FMS cont.sys. 2.Deg. of aut.	1.FMS cont.s. 2.Mach.-tool cont.sys. 3.Part type 4.% of MC 5.Deg.of aut. 6.Investment

Table 4(b)

ATTRIBUTE RANKING FOR CORE SETS

STRATA SCENARIO " TYPE OF PRODUCTION - LOW FLEXIBILITY / >MID OUTPUT "

	CORE SET 1 (4 FMS cases)	CORE SET 2 (3 FMS cases)
Impact of attributes:		
1.FMS type	+1	+0
2.M - T control system	+0	+1
3.Deg.of integration	+0	+0
4.FMS control system	+0	+0
5.Degree of automation	+0	+1
6.Total number of M-T	+3	+4
7.Quality control	+2	+3
MOST IMPORTANT ATTRIBUTES:	1.Degree of integration 2.M - T control system 3.Degree of automation 4.FMS control system	1.Deg. of integration 2.FMS control system 3.FMS type

STRATA SCENARIO " TYPE OF PRODUCTION - HIGH FLEXIBILITY "

Table 5

	CORE SET 1	CORE SET 2	CORE SET 3
most important	Deg.of automation	FMS control system Deg. of automation	FMS control sys. Mach.-tool cont.sys. Part type % of mach.centres Deg. of automation Investment
important	FMS control system Part type Investment Deg. of integration	Part type Investment Deg. of integration	Deg. of integration
no impact	Country Industry Part size FMS type Output volume Quality control Mach.-tool cont.sys. Total N of mach.-tools % of mach. centres Tool change Scrap removal	Country Industry Part size FMS type Output volume Quality control Mach.-tool cont. sys. Total N of mach.-tools % of mach. centres Tool change Scrap removal	Country Industry Part size FMS type Output volume Quality control Total N of mach.-tl. Tool change Scrap removal
	1981	1983	1985,1986

THE CORE SET'S STATISTICS AND REPRESENTATIVE FMS CASES

Table 6

ATTRIBUTES	CORE SET 1			CORE SET 2			CORE SET 3			Core set's representatives			
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	1	1	2	3
Country Date	-	-	-	-	-	-	-	-	-	FRG 1984	USSR 1983	Japan 1983	USA 1987
Investment	2.41	1.5	3.5	2.82	1.2	4.5	13.25	7	18	1.5	2.5	4.5	13
Part type	-	-	-	-	-	-	-	-	-	Prizm.	Prizm.	Prizm.	Prizm.
Industry	-	-	-	-	-	-	-	-	-	M-T bld	M-T bld	Mechan.	Defence
Part size	700	400	1000	700	200	1000	1000	700	>1000	700-1000	700-1000	700-1000	700-1000
FMS type	Shop	-	-	Shop	-	-	Shop	-	-	Shop	Shop	Shop	Shop
Output volume	11000	2000	25000	3000	-	6000	8875	-	25000	5000	4000	6000	5000
Deg.of autom.	50.48	33.33	66.67	62.22	53.33	66.67	76.67	73.33	80.00	53.33	33.33	60.00	80.00
Deg.of integ.	Low	-	-	Med.	-	-	Med.	-	-	Low	Low	Med.	High
Quality cont.	-	-	-	-	-	-	-	-	-	visual	visual	auto	auto
FMS cont.sys.	DNC	-	-	DNC	-	-	DNC	-	-	DNC	DNC	DNC	DNC
M-T cont.sys.	CNC	-	-	CNC	-	-	CNC	-	-	CNC	CNC	CNC	CNC
N of M-Tools	5	2	8	10	7	15	13	6	30	7	5	7	6
% of M-centr.	85.41	42.86	100	69.46	40	100	100	100	100	42.86	80.00	71.43	100
Tool change	-	-	-	-	-	-	-	-	-	s/auto.	manual	auto	auto
Scrap removal	No	-	-	Yes	-	-	Yes	-	-	No	No	No	Yes
Batch size	6.4	2	10	5.2	1	10	6.5	1	10	5	3	4	10
Prod.variety	128.4	62	200	109.2	70	200	290.5	72	550	200	62	70	90

STRATA SCENARIO " TYPE OF PRODUCTION - LOW FLEXIBILITY / >MID OUTPUT "

Table 7

	CORE SET 1	CORE SET 2
most important	Deg. of integration M - T control system Degree of automation FMS control system	Deg. of integration FMS control system FMS type
important	FMS type Quality control Total N of M-T	M - T control system Degree of automation Quality control Total N of M-T
no impact	Country Industry Part type Part size Output volume % of mach.centres Tool change Investment Scrap removal	Country Industry Part type Part size Output volume % of mach.centres Tool change Investment Scrap removal
	mid output	high output

STRATA SCENARIO "TYPE OF PRODUCTION - HIGH FLEXIBILITY / HIGH OUTPUT "

Table 8

	CORE SET 1	CORE SET 2
most important	Total N of M-T	Scrap removal Industry Total N of M-T
important	Scrap removal Industry Part type M - T control system Tool change	Part type FMS control system Quality control
no impact	Country FMS type Part size Output volume % of mach.centres FMS control system Quality control Degree of automation Investment	Country FMS type Part size Output volume % of mach.centres M - T control system Tool change Degree of automation Investment
	1979	1984

STRATA SCENARIO " ECONOMIC RATIONALITY - CHEAP + SIMPLE "

Table 9

	CORE SET 1	CORE SET 2	CORE SET 3
most important	M-T Control system Deg.of automation FMS control system	FMS control system Deg.of automation M-T Control system Investment	M-T Control system FMS control system Investment
important	Part type Investment Quality control Industry % mach. centr. Tool change	Part type Quality control Industry Part size FMS type Tool change Scrap removal	Deg.of automation Industry Part type Quality control Scrap removal
no impact	Country Batch size Part size FMS type Output volume Product variety Total N of M-T Scrap removal	Country Batch size Output volume Product variety Total N of M-T % mach. centr.	Country Batch size Part size FMS type Output volume Product variety Total N of M-T % mach. centr. Tool change

STRATA SCENARIO " ECONOMIC RATIONALITY - EXPENSIVE + SOPHISTICATED "

Table 10

	CORE SET 1	CORE SET 2
most important	Country Investment FMS type FMS control system M - T control system Industry	Country Investment FMS type FMS control system M - T control system Industry Part type Total N of M-T Scrap removal
important	Part type Total N of M-T % of mach.centres Scrap removal Degree of automation Quality control	% of mach.centres Degree of automation Quality control
no impact	Part size Output volume Tool change Product variety Batch size	Part size Output volume Tool change Product variety Batch size

STRATA SCENARIO " ECONOMIC RATIONALITY - CHEAP + SOPHISTICATED "

Table 11

CORE SET 1

most important	FMS control system M - T control system % of mach. centres Tool change Investment Degree of automation Batch size
important	Product variety
no impact	Country Industry FMS type Part type Part size Output volume Total number of M-T Quality control Scrap removal

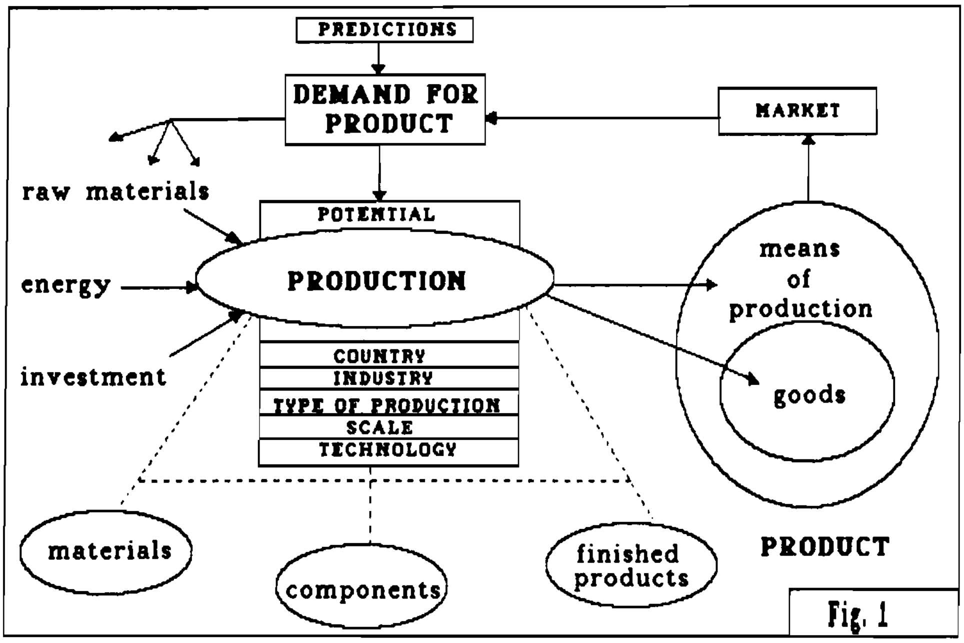

PREDICTIONS
DEMAND FOR PRODUCT
MARKET
raw materials
energy
investment
POTENTIAL
PRODUCTION
COUNTRY
INDUSTRY
TYPE OF PRODUCTION
SCALE
TECHNOLOGY
means of production
goods
PRODUCT
materials
components
finished products

Fig. 1

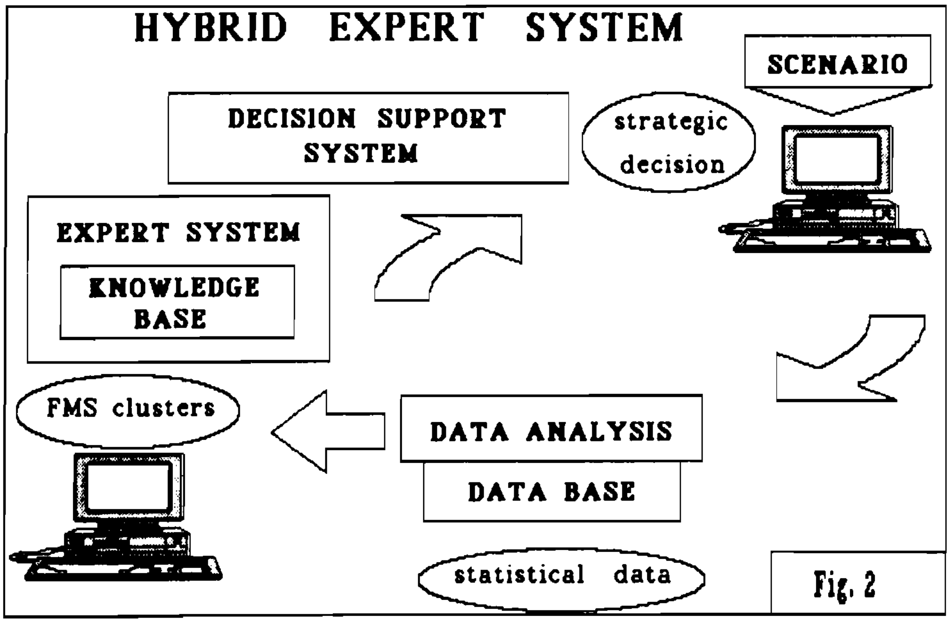
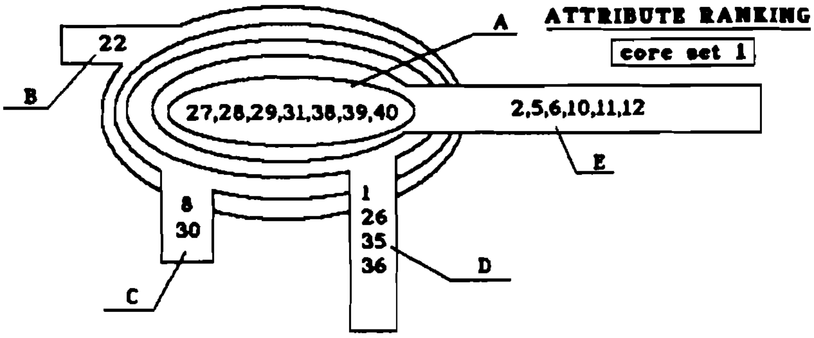
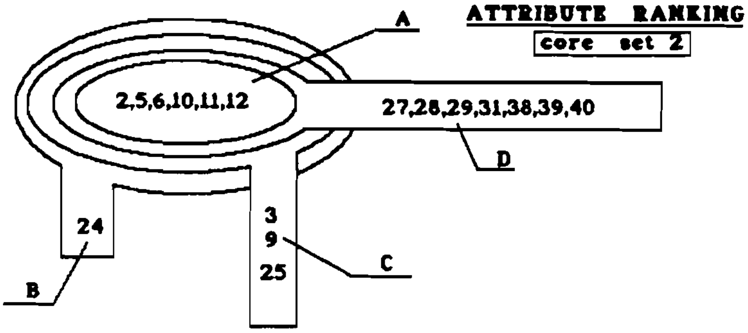

HYBRID EXPERT SYSTEM
SCENARIO
DECISION SUPPORT SYSTEM
strategic decision
EXPERT SYSTEM
KNOWLEDGE BASE
FMS clusters
DATA ANALYSIS
DATA BASE
statistical data

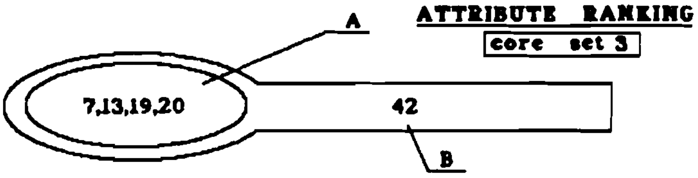
Fig. 2



A - core set & impact of the factor : Degree of Automation.
B - impact of the factor: FMS Control System Type.
C - impact of the factor: Part Type.
D - impact of the factor: Investment level.
E - impact of the factor: Degree of Integration.



A - core set & impact of the factors: FMS Control System Type,
Degree of Automation.
B - impact of the factor: Part Type.
C - impact of the factor: Investment level.
D - impact of the factor: Degree of Integration.



A - core set & impact of the factors: FMS Control System Type,
Degree of Automation.
Part Type.
Investment level.
B - impact of the factor: Degree of Integration.

Fig. 3

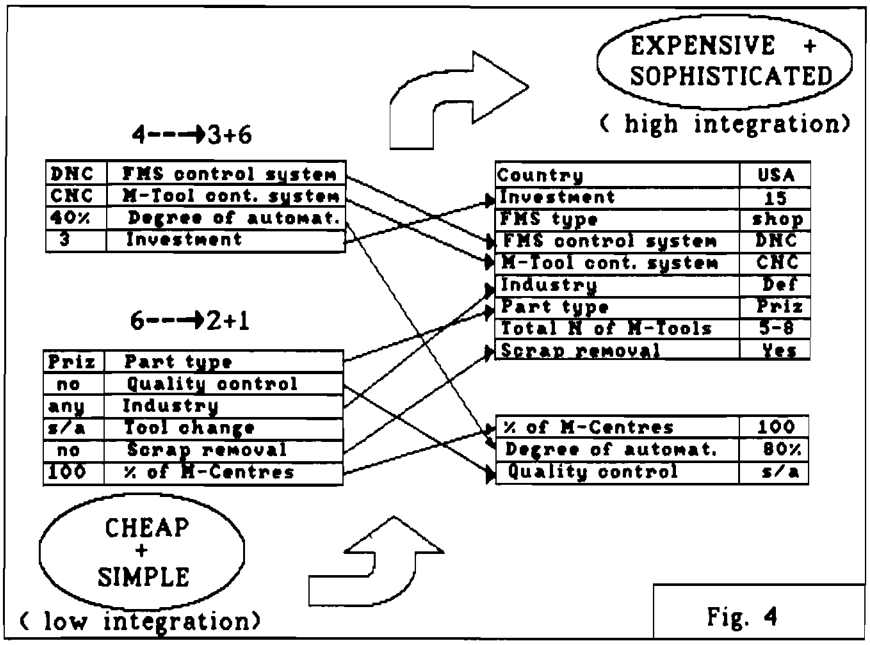

EXPENSIVE + SOPHISTICATED
(high integration)
4---→3+6
DNC | FMS control system
CNC | M-Tool cont. system
40% | Degree of automat.
3 | Investment
Country | USA
Investment | 15
FMS type | shop
FMS control system | DNC
M-Tool cont. system | CNC
Industry | Def
Part type | Priz
Total N of M-Tools | 5-8
Scrap removal | Yes
6---→2+1
Priz | Part type
no | Quality control
any | Industry
s/a | Tool change
no | Scrap removal
100 | % of M-Centres
% of M-Centres | 100
Degree of automat. | 80%
Quality control | s/a
CHEAP + SIMPLE
(low integration)

Fig. 4

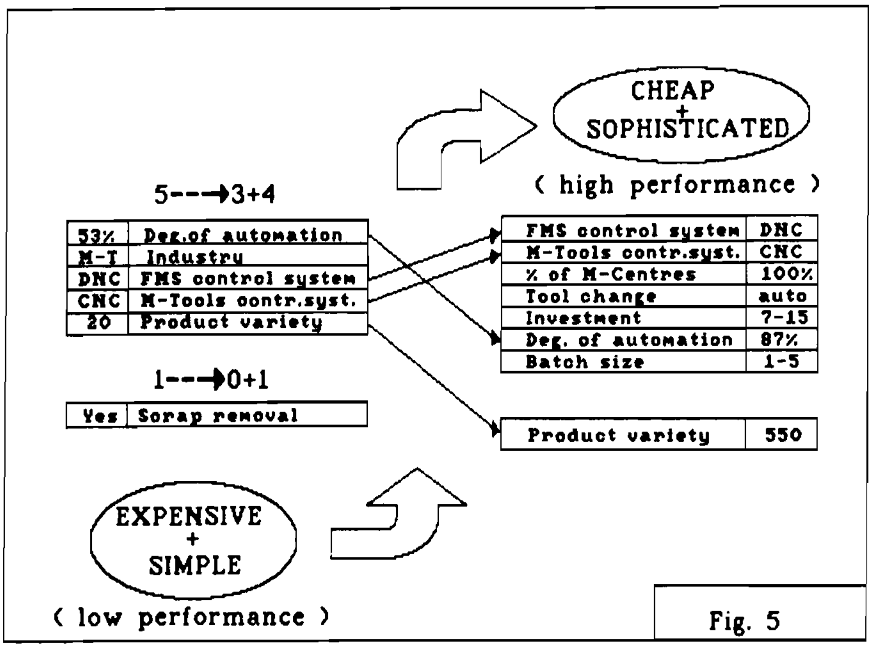

CHEAP + SOPHISTICATED
(high performance)
5---→3+4
53% | Deg.of automation
M-T | Industry
DNC | FMS control system
CNC | M-Tools contr.syst.
20 | Product variety
FMS control system | DNC
M-Tools contr.syst. | CNC
% of M-Centres | 100%
Tool change | auto
Investment | 7-15
Deg. of automation | 87%
Batch size | 1-5
1--→0+1
Yes | Scrap removal
Product variety | 550
EXPENSIVE + SIMPLE
(low performance)

Fig. 5

CIM and the Economy: Clues for Empirical Analysis

by

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Contents

1. High-tech and the economic system

The global community is changing its contour rapidly toward the 21st century. IIASA's computer integrated manufacturing (CIM) project has tried to assess the impact of technological change, which is already underway and is expected to become widely diffused toward the 21st century, on our global community. The nations in the world have become more interdependent today than anytime in history, and any economic analysis cannot be concluded by simply looking into a single country case. Especially important seems to be the case of computer-communication-control (C-C-C) technology which has found its way into new products, new production processes, and new social organizations. Indeed, C-C-C has become the basis of our society today.

The world is beleaguered by environmental disruption and resource exhaustion. Continued economic expansion seems to be incompatible with the limits imposed by the environment. Here too, technological change centering around C-C-C and reorganization of our economies incorporating such change seems to be the only feasible solution to safeguard sustainability of our global community.

In industrialized countries, the structure of the economy is changing radically reflecting increased introduction of electronic devices leading to robotization and automation. Information as capital, input, and output, although intangible, is changing the social structure to a horizontal network rather than hierarchical command system. Occupational profile is also undergoing rapid shift both in terms of industrial sectors and occupational categories. This may create mismatch and adjustment problem. The role played by gender and by age may also be affected. Among nations, the differentials in the diffusion of high-tech result in trade friction, investment friction, and technology friction, and point to the danger of collision of interest.

In industrializing countries, where population pressure and income differentials are pressing, industrialization and export drive taking advantage of cheap labor can no longer be among their development options. Electronics revolution in industrialized countries with its capacity to replace human labor with machinery precludes such a strategy. For resource exporting countries, resource-conserving technological change in industrialized countries results in stagnant exports for them. What is more, environmental concern on a global scale constrains the desire for industrialization.

Industrialized countries and industrializing countries, market economies and planned economies are all connected by international trade, direct foreign investment, technology flows, population migration, and global environment. Is the high-tech growth path a blessing for us all? This seems to be the question we ultimately have to address ourselves. To this end, we start by collecting empirical evidence as to the socio-economic impact of C-C-C technology.

Research and development (R&D), technological progress, capital formation, production, exports, direct foreign investment, employment, environmental impact, etc. are interwoven. For example, if new technology emerges as a result of R&D effort, existing production facility will become obsolete and new capital formation will be carried out. In an economy where demand is expanding, the introduction of new technology will be facilitated. As a consequence, production will become more efficient, due, for example, to labor saving and/or resource saving, resulting in lower prices. At the same time, quality of the products will be improved. This in turn may mean export promotion. Increased production and resultant increase in employment will eventually make the labor market tighter, inviting wage hikes. Changing prices signal the direction of desirable technological change. Labor is a scarce factor of production in industrialized countries; so is the environment in a wide sense including not only raw materials but also clean air and water, among others. Technological progress will be induced in the direction of conserving these scarce factors.

The complex interrelationship among these diverse aspects can only be captured by an econometric model which incorporates relevant variables. This is easily said. In practice, however, construction of an econometric model to suit our purpose is a difficult endeavor. First of all, disaggregated analysis is needed in oder to focus on the industrial sectors related to C-C-C technology, but construction of a multi-sector model is always an extremely demanding job. In a newly energing field such as the one we are discussing in this paper, the problem is often compounded by the lack of data. Secondly, international linkages are needed in order to assess international repercussion of the diffusion of high-tech. Ideally, this must be accomplished by constructing multi-sectoral country models. Sectoral classification and other specifications have to be consistent among themselves. Only then they can be linked by trade matrixes.

The purpose of this note is to demonstrate the feasibility of empirical examination within our context. In the following sections, some of the key factors are discussed which link technology with the functioning of an economy taking the case of a multisector industrial model constructed by the present author. We then summarize the methodology and results provided by contributors to the volume which is devoted to the examination of economic and social impacts of CIM.

2. R&D and machinery sectors

Research and development (R&D) is an important economic activity in today's economy. Production of technological knowledge is undoubtedly a key factor for an economy in order to gain production efficiency while achieving resource conservation. However, economic theory and statistical accounts have not dealt with R&D in a systematic manner.[1] One difficulty is the fact that the benefit of R&D activity does not remain totally within a sector which undertakes it. Rather, the benefit spills over to the entire economy through improved quality and/or lower prices of intermediate inputs and capital equipment for other industrial sectors.

A practical method was proposed by Terlecskyj [1980, 1982]. Starting from the R&D expenditures undertaken in individual industrial sectors, he tried to distribute the benefit to the purchasing sectors by the use of information obtained from input-output tables.

Based on Terlecskyuj's methodology and empirical data from Japan which include annual R&D data, annual input-output tables, and fixed capital formation matrixes from 1970, 1975, 1980, and 1985, an estimation was made on the annual flow of R&D benefit accureing to industry and final demand.[2] Industry is divided into standardized [illegible] sectors and final demand in broken down into private consumption, government consumption, private investment, government investment, exports, etc. Fixed capital formation matrix is employed in order to distinguish the sector where capital formation is carried out. This process is needed because fixed capital formation among final demand items in the input-output tables only shows the amount of output of a particular sector going into investment.

In addition, due consideration is given to the technology imports. Both domestic R&D and technology imports are appropriately lagged in order to take into account of the time required for R&D to meterialize in the form of new products and new production processes.[3]

Table 1 below is the summary pertaining to machinery sectors. Comparisons of R&D activities and benefit received reveal that precision instrument, electrical machinery, and general machinery sectors are the typical examples of net provider of R&D benefit to other industrial sectors.

3. Diffusion of C-C-C

Electronics technology is already having a tremendous impact on our society, and yet full impact is yet to unfold toward the 21st century and beyond. As an indicator of such development, one can look at production statistics of semiconductors, the progress of degital communication, or the development of database technology. They all represent electronics revolution. In this section, we examine the diffusion process of mainframe computers, NC metalworking machines, industrial robots, and automatic vending machines as representing C-C-C technology. Figure 2 represents the result of simulation of C-C-C diffusion based on a multisectoral industry model COMPASS (solid lines show actual figures and dotted lines calculated values). Represented on the vertical axis is the share of C-C-C related machinery and equipment in total capital stock in respective industrial sectors.

In the model, diffusion rates (RK---i) in respective sectors are explained by the relative price of labor and capital (WHRi) and the real capital formation (IPi).

$$\left.\begin{array}{l} \mathrm{RKCOMi} \\ \mathrm{RKNCi} \\ \mathrm{RKROBOi} \\ \mathrm{RKVENDi} \end{array}\right\} = f\ (\ \mathrm{WHRi},\ \mathrm{IPi})$$

The reasoning behind the specification is that the diffusion of new technology would be accelerated as the relative price of capital beccame lower, either due to appreciation of wage level or cheapening of capital equipment prices. Capital formation exhibits fluctuations reflecting the changes in demand-supply gap and/or the levels of interest rate. It can be assumed that the introduction of new technology would be easier when investment is being carried out anyway in order to cope with rising demand. Empirical examination of the function was fairly good.

Tables 2 and 3 represent the diffusion of NC metal working machines, industrial robots, and FMS in Japanese industry based on a MITI survey in 1987.[4] The number of machines at the time of survey in 1987 stood at 70,465, of which 28,195 belonged to general machinery sector, 11,932 to electrical machinery sector, 20.123 to motor vehicles sector, and 3,520 to precision instrument sector.[5] The diffusion rate in terms of the number of machines stood at 10.9% in the same year. Among the industrial sectors, general machinery and electrical machinery sectors had the highest rate, recording 12.1% and 13.2%, respectively. However, more relevant figure seems to be diffusion rate in value terms because NC machines are more efficient and, of course, more expensive, than conventional metalworking machines. 1987 is the only year when such data is available, and the diffusion rate in value terms is recorded at 33.5% for all industries.

In the case of industrial robots, the 1987 Survey reports that there exist 47,308 units in Japanese industry. The 1973 figure stood at 3,058 (of which 2,735 were in machinery sectors) and the 1981 figure stood at 14,158. The same source reveals that Japanese industry posessed 259 FMSs as of 1987.

The Survey also reveals vintage of metalworking machinery. The units installed within last three years stood as follows.

NC metal cutting machines	37.4%
NC secondary metal working machinery	35.9%
Industrial robots	46.6%
Flexible manufacturing system	47.1%

The figures indicates how rapid the diffusion of new technology has been. At the same time, such trend seems to justify the use of average age of capital stock as a proxy for quality improvement of production equipment.

4. Structural change of capital formation

New technology is embodied in new capital equipment. The diffusion of C-C-C has its impact on an economy through fixed capital formation. Thus, we turn to private fixed capital formation, and examine the changes in sectoral composition of the supplying sector for this particular demand category. The basis of our analysis is annual input-output tables for the Japanese economy in the past 10 years.[6] The sectoral ratio of supplying sector for final demand is sometimes called converters. Table 4 shows converters for private fixed capital formation, focusing on machinery sectors including general machinery, electrical machinery, motor vehicles, other transport equipment, and precison instrument. Construction sector is also listed for comparison. Needless to say, the table shows the share of each sector, total being unity.

The table reveals that the share of machinery sectors total has steadily increased during the 1980-1985 period. The figures for 1975 and 1980 are not particularly different, and closer examination of annual figures confirms this point. We may say that the structural change of private fixed capital formation started around 1980 in Japan. What characterizes the new trend is the rising share of machinery sectors, especially electrical machinery and general machinery. The share of precision instrument has also risen steadily. Thus, during 1980 and 1985, the share of machnery sectors total has risen nearly ten percentage points, from 28.7% to 38.3%. During the same period, electrical machinery has gained most, expanding its share from 8.7% to 13.2%. General machinery sector increased the share from 12.3% to 16.7%. The share of precision instrument is inherently smaller than these sectors, but it has also increased the share from 0.9% to 1.3%. In constrast, the construction sector dropped its share from around 60% in 1975 and 1980 to less than 50% in 1985.

This is a firm evidence of the nature of technological change that is taking place in our economies.

The above observation is based on current prices. It is important to note that the price of C-C-C related products has exhibited secular decline during this period. Current price figures provide a picture which is a mixture of rapid diffusion of C-C-C technology and declining prices. What is lacking in an appropriate measure of quality improvement. There are sporatic attempts to estimate quality-adjusted price indexes in this field. According to their results, for example, the price of mainframe computers has dropped from the base year level of 100 in 1970 to 21 in 1980 and 7 in 1987; in the case of industrial robots, it has dropped from 100 in 1970 to about 40 in 1985. The deflator for electric machinery on SNA basis showed a deline of about seven percentage points, whereas that for general machinery has risen by about 60% during the 1970-1985 period.[7] Therefore, we can say that the importance of C-C-C related sectors such as electric machinery and precision instrument must have risen at a much faster rate than is suggested by the current price figures.

5. High-tech and exports

It is revealed from various surveys that the introduction of high-tech is motivated by labor saving. Other factors include quality improvement of products, increase in production capacity, shortening of lead-time, flexibility in design and production, among others. Some of these factors contribute to lowering of product prices, but some of them are not reflected in prices. Typical factor is quality improvement. However, capacity increase (presumably without much increase in marginal cost, because, for one thing, automatic operation is possible without much increase in labor input), shorter lead time, and added flexibility all work toward quick response to changes in the market.

Japanese exports continued to expand despite rapid appreciation of the yen exchange rate after the G5 agreement in 1985. One may suspect that non-price factors such as quality and flexibility, made possible by the C-C-C technology, are the contributing factors.

In order to examine this hypothesis in an empirical context, we introduced variables representing the diffusion of CV-C-C technology in export functions of the multisector industry model. The model explains exports (in real terms) in each industry (ERi) by the world industrial production (YWORLD), relative prices which is the ratio of export prices adjusted for the exchange rate fluctuation (REX*PEi) and the world price (PUNi), and proxy variables describing the diffusion of mainframe computers, NC machines, and industrial robots (RKCOMi+RKNCi+RKROBOi). Exchange rate in this specification is represented by dollar per yen.

ERi = f (YWORLD, REX*PEi/PUNi, RKCOMi+RKNCi+RKROBOi)

The function was tested for general machinery, electrical machinery, motor vehicles, and precision instrument and the results were good. It should be noted that the movement of prices already captures the effects of high-techdiffusion. That is, export price in model COMPASS is obtained as a function of corresponding producing sector price. This in turn is explained as a function of unit labor cost and unit material cost.[8] Material cost is then specified reflecting the input structure of respective industrial sector. When C-C-C related prices go down, benefit accrues to the sectors which use these products in their production processes and intermediate inputs. Lower prices of electronics-related goods thus spreads to other sectors of te economy.

In addition, as the significance of C-C-C technology becomes widely recognized internationally, countries not only imports C-C-C related goods but also try to initiate their production. This means that the Japan's position as a supplier of these goods and technology is even more highted. This is reflected in the high elasticity of Japanese exports vis-a-vis the growth of world economy. The causal chain is closed by referring to the fact that R&D is Japan is quite active, especially in C-C-C related civilian sectors. It is shown that R&D expenditures by electric machinery sector have expanded quite rapidly and exceed one quarter of total R&D spending, and that large portion is going into electronics field.[9]

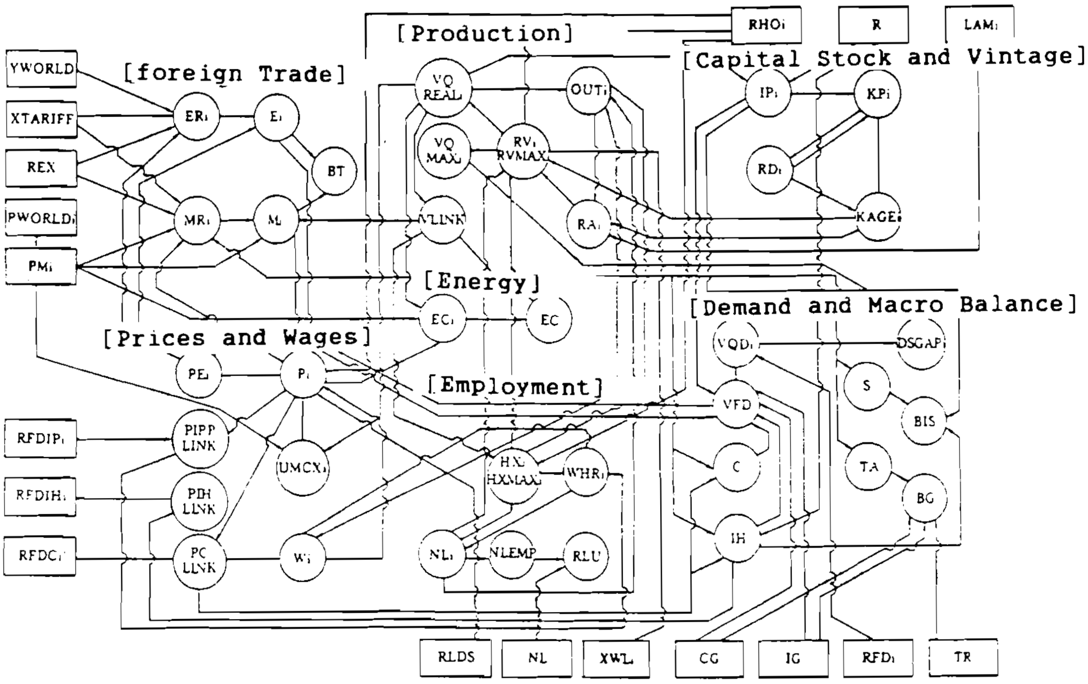
Table 5 shows the export structure of Japan in the 1980s. The largest component of Japan's exports is machinery (SITC 7). The share of machinery in total stood at 58% in 1980, 68% in 1985, and 74.4% in 1988. This compares favorably with that in Europe where it stands around 33% (1985) and in the United States where it stands around 46%. The raio in Asian countries (excluding Middle East) where the wave of industrialization is accelerating, the ratio stood at 14% in 1980, which jumped to 22% in 1985.

In the case of imports, on the other hand, the ratio of machinery in total is increasing but the level is low at 9%. Comparable figures for Europe and the United States stood at 27% and 42%.

Table 6 refers to the share of respective countries/area in total world exports. In the machinery exports, Japan's share reached about 20% in recent years, a figure nearly 5 percentage points higher than in 1980. This figure is already higher than that in the United States where it stood at 16%. The share of Asia (other than Middle East) was recorded at 4% in 1980 and 7% in 1985.

Figure 1. Simplified flow diagram of COMPASS

[Foreign Investment]	[Environment and Resources]	[High-tech]	[Research and Development]
IFi QFi	IZi KZi Zij MRAW MFUEL, etc.	RKCOMi RKNCi RKROBOi RKVENDi	R&Di QPATi



[Household]	[Demography and Time Budget]	[Quality of Life]
Ya Sa, SSa	N, NM, NF RNLMa RNLFa HMa, HFa	NNW or MEW KH, KCD, KG HL Z

Figure 2. Diffusion of high-tech, a simulation result

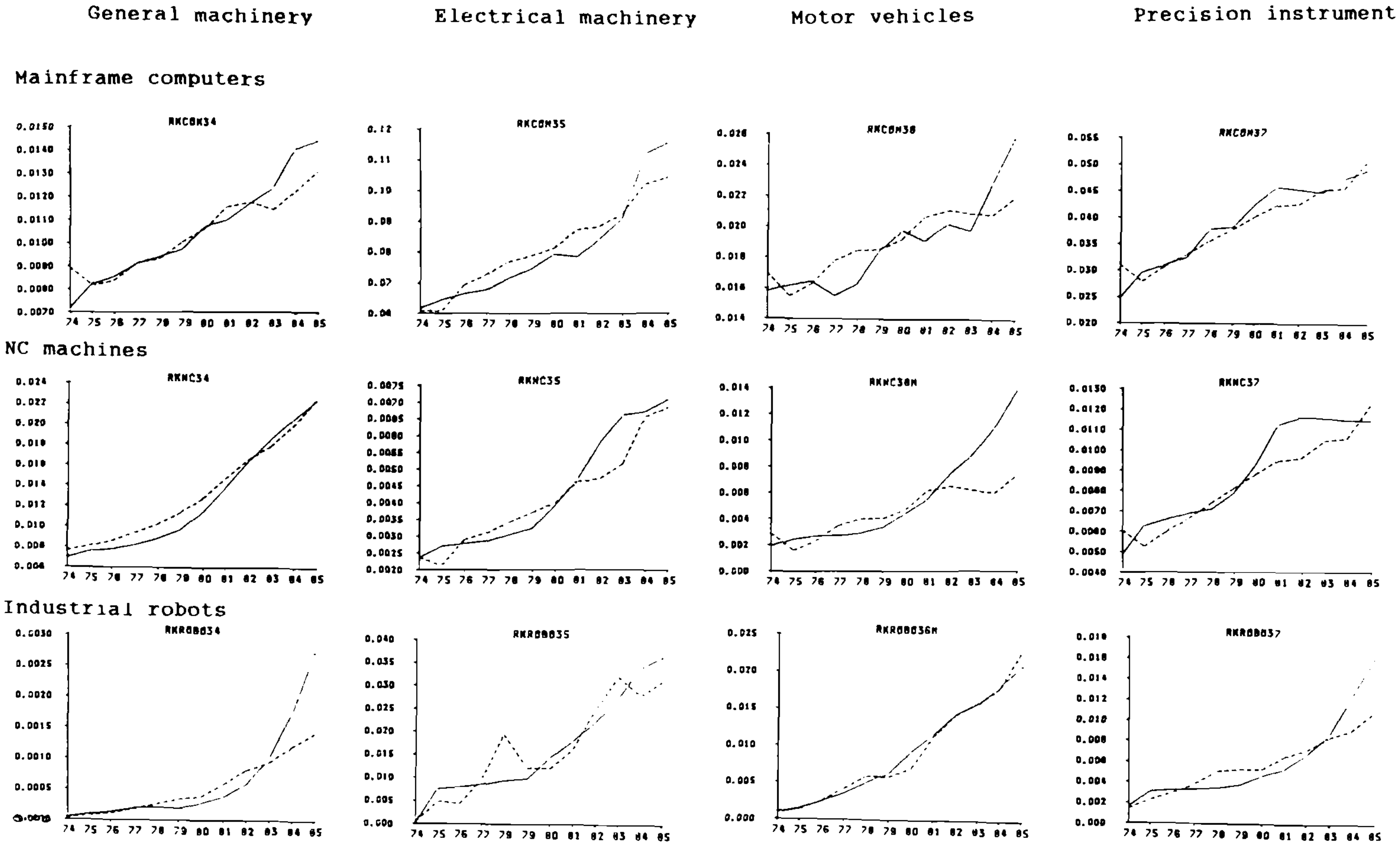


Table 1. R&D activity conducted and R&D benefit received in machinery sectors
(unit: billion yen, 1970 prices)

	General machinery	Electrical machinery	Motor vehicles	Precision instrument
a. R&D activities conducted				
1975	201.4	637.1	250.2	40.4
1976	230.8	653.4	285.2	39.9
1977	230.2	625.1	274.8	36.6
1978	205.2	597.5	254.8	39.0
1979	238.5	611.6	275,5	53.2
1980	244.8	632.3	330.6	64.3
1981	241.5	707.1	394.3	66.7
1982	260.8	777.4	409.4	73.9
1983	284.4	838.6	428.9	82.7
1984	296.7	989.3	506.5	85.6
1985	336.4	1146.7	550.1	100.3
1986	378.8	1289.1	604.8	117.4
1987	418.3	1486.7	656.1	130.7
b. R&D benefit received				
1975	115.0	165.0	181.7	10.6
1976	106.7	179.5	185.4	11.0
1977	121.7	176.8	196.1	11.2
1988	113.8	166.6	187.3	13.0
1979	123.8	169.6	192.7	14.6
1980	128.8	182.9	216.5	16.6
1981	128.2	200.6	229.5	16.1
1982	145.8	231.0	238.2	18.3
1983	157.2	263.5	254.8	20.2
1984	171.6	331.1	289.1	20.4
1985	189.6	389.4	320.3	23.7
1986	219.5	474.8	357.1	28.0
1987	244.7	540.6	391.7	31.1

Source: Statistical Data Bank Project, The University of Tsukuba. Fixed Capital Formation and R&D Benefit. 1990.
Note: For details of methodology, see Kimio Uno, Measurement of Services in an Input-Output Framework, Elsevier Science Publishers, 1989.

Table 2. Number of NC machines in use

(unit: number of units, million yen, %)

	Sector Total	1967 Survey[a] Number[c]	1973 Survey[a] Number[c]	1973 Survey[a]' Number[d]	1981 Survey[b]' Number[d]	1987 Survey[b] Number	 Value
	All industries	769	5.402	4.861	19.549	70.465	670,388
31	Iron and steel	47	85	n a	n.a.	1,572[e]	15,092[e]
32	Nonferous metals	11	254	n a	n.a		
33	Fabricated metals	74	202	n a	n a.	2,537	24,344
34	General machinery	264	2.765	2.783	9.378	28,195	284,984
35	Electrical machinery	85	832	832	3.185	11,932	101,343
36	Transport equipment	257	948	948	5.404	21,981	213,330
36M	Transport equipment, Motor vehicles			604	4.293	20,123	189,853
37	Precision instrument	71	298	298	1,582	3,520	22,850
	Diffusion rate (=B/A),%						
	All industries	0 1	0 7	0 9	3 7	10.9	33.5
31	Iron and steel	0 0	0 2			9.0[e]	33 7[e]
32	Nonferous metals	0 1	1 1				
33	Fabricated metals	0.1	0.2			7.4	34.1
34	General machinery	0.1	1.1	1.2	4.8	12.1	40.5
35	Electrical machinery	0 1	0 6	0.9	3.9	13.2	35.9
36	Transport equipment	0 1	0 4	0 5	2.6	9.7	26.0
36M	Transport equipment, Motor vehicles			0 4	2.3	9.6	24 7
37	Precision instrument	0 1	0 4	0 5	3.3	8.9	40 1

Table 3. Number of industrial robots and FMS in use

(unit: number of units, %)

	Sector	1967 Survey Number	1973 Survey Number[c]	1981 Survey[b]' Number[d]	1987 Survey[b] Number
	Industrial robots				
	All industries	n a.	3.058	14,158	47,308
31	Iron and steel		53	n.a.	750[e]
32	Nonferous metals		150	n.a.	
33	Fabricated metals		120	n.a.	1,372
34	General machinery		205	1,253	5,380
35	Electrical machinery		423	3,859	18,475
36	Transport equipment		1,610	8,383	20,901
36M	Transport equipment, Motor vehicles		1,592	8,315	20,229
37	Precision instrument		495	663	2,094
c.	Flexible manufacturing system				
	All industries	n.a	n.a.	n.a.	259
31	Iron and steel				
32	Nonferous metals				
33	Fabricated metals				
34	General machinery				171
35	Electrical machinery				44
36	Transport equipment				40
36M	Transport equipment, Motor vehicles				21
37	Precision instrument				2

Table 4. Supplying sectors for private fixed capital formation

(unit: ratio of total)

Code	Sector names	1975	1980	1981	1982	1983	1984	1985
34.	General machinery	0.1394	0.1230	0.1328	0.1297	0.1321	0.1378	0.1665
35.	Electrical machinery	0.0806	0.0872	0.1217	0.1070	0.1252	0.1417	0.1317
36M.	Motor vehicles	0.0518	0.0535	0.0540	0.0576	0.0581	0.0581	0.0487
36S.	Other transport equipment	0.0116	0.0177	0.0112	0.0187	0.0177	0.0166	0.0237
37.	Precision instrument	0.0067	0.0094	0.0090	0.0098	0.0102	0.0110	0.0132
	Machinery sectors total	0.2899	0.2872	0.3286	0.3223	0.3429	0.3650	0.3835
	Construction	0.6054	0.6097	0.5562	0.5655	0.5532	0.5295	0.4947
	Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Source: Kimio Uno, Annual Input-Output Tables in Japan, 1975-1985, 1990.

Note: Total includes other sectors such as furniture and fixture, fabricated metals, and wholesale and retail trade.

Table 5. Commodity composition of exports of selected countries and areas

IN PERCENT

ORIGIN OR DESTINATION → ↓ SITC: COMMODITY CLASSES		YEAR	WORLD	MARKET ECONOMIES			CENTRALLY PLANNED ECONOMIES	EUROPE	U.S.A.	JAPAN
				DEVE LOPED	DEVELOPING					
					TOTAL	OPEC		TOTAL		
COMMODITY COMPOOSITION OF THE WORLD EXPORTS SELECTED REGIOONS										
0-9	TOTAL ALL COMMODITIES	1980	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		1982	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		1983	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		1984	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
		1985	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
0&1	FOOD LIVE ANIMALS AND BEVERAGES TOBACCO	1980	10.0	10.2	10.1	1.2	8.1	9.6	14.0	1.2
		1982	10.2	10.2	11.4	1.3	8.9	10.0	13.0	1.0
		1983	10.2	9.9	12.3	1.6	6.6	9.7	13.7	0.9
		1984	9.8	9.4	12.2	1.9	6.1	9.5	12.8	0.8
		1985	9.2	8.7	11.8	2.1	6.4	9.2	10.7	0.7
2&4	CRUDE MATERIALS OILS AND FATS (FUELS EXCLUDED)	1980	6.9	6.8	7.1	1.7	7.4	4.2	11.9	1.2
		1982	6.1	6.0	6.3	1.2	6.1	3.7	10.0	1.0
		1983	6.2	6.0	6.8	1.4	5.9	3.9	10.2	1.0
		1984	6.5	6.3	7.4	1.6	6.1	4.3	10.5	0.9
		1985	6.2	5.7	7.6	1.7	6.2	4.0	8.8	0.8
3	MINERAL FUELS AND LUBRICANTS RELATED MATERIAL	1980	24.1	7.0	61.4	94.8	25.8	8.3	3.7	0.4
		1982	23.2	8.4	55.8	94.1	30.0	9.8	6.2	0.3
		1983	21.0	8.2	49.3	92.5	31.0	9.8	4.9	0.3
		1984	19.7	7.9	45.1	91.7	31.3	9.7	4.4	0.3
		1985	18.7	8.0	43.3	91.1	29.9	9.4	4.8	0.3
5	CHEMICALS	1980	7.0	9.7	1.7	0.5	5.0	11.1	9.6	5.1
		1982	7.2	9.5	2.2	0.7	5.5	11.2	9.6	4.5
		1983	7.6	10.0	2.5	1.0	5.5	11.8	10.1	4.6
		1984	7.7	10.0	2.6	0.7	5.6	12.1	10.6	4.4
		1985	7.9	10.0	2.8	0.9	6.2	12.2	10.3	4.3
7	MACHINERY AND EQUIPMENT TRANSPORT	1980	25.6	34.7	5.3	0.5	26.5	32.0	39.0	58.4
		1982	27.7	36.8	7.3	0.8	25.0	32.8	42.0	61.3
		1983	28.7	37.0	9.3	0.9	25.3	32.0	42.1	63.8
		1984	29.7	37.8	11.0	1.1	24.7	31.5	42.4	66.6
		1985	31.1	39.1	11.9	1.2	25.1	32.5	45.7	67.8
6&8	OTHER MANUFACTURED GOODS	1980	24.0	29.4	13.5	1.2	19.1	32.9	17.9	32.4
		1982	23.1	27.0	16.1	1.6	17.6	30.6	15.9	30.8
		1983	23.6	26.8	18.7	2.3	17.1	30.7	15.5	28.3
		1984	23.9	26.3	20.6	2.7	17.4	31.0	14.7	26.0
		1985	24.2	26.4	21.4	2.8	17.0	31.1	14.4	25.0

Table 6. Origin of world exports

ORIGIN OR DESTINATION → ↓ SITC COMMODITY CLASSES		YEAR	WORLD	MARKET ECONOMIES			CENTRALLY PLANNED ECONOMIES	EUROPE	U.S.A.	JAPAN
				DEVE LOPED	DEVELOPING					
					TOTAL	OPEC		TOTAL		
			/1.2.5	/3.4.5	/3.4.5	/6	12.5			
ORIGIN OF EXPORTS OF MAJOR COMMODITY CLASSES										
0-9	TOTAL ALL COMMODITIES	1980	100.0	62.9	28.3	15.3	8.8	40.1	10.8	6.5
		1982	100.0	63.2	26.7	12.1	10.1	38.5	11.2	7.5
		1983	100.0	63.6	25.4	10.0	11.0	38.4	10.8	8.1
		1984	100.0	64.3	25.1	8.9	10.6	37.4	11.1	8.9
		1985	100.0	65.5	23.9	8.0	10.5	39.0	10.7	9.1
7	MACHINERY AND EQUIPMENT TRANSPORT	1980	100.0	85.0	5.9	0.3	9.1	50.0	16.5	14.8
		1982	100.0	83.9	7.0	0.4	9.1	45.6	17.0	16.6
		1983	100.0	82.1	8.2	0.3	9.7	42.9	15.9	18.0
		1984	100.0	81.8	9.3	0.3	8.9	39.8	15.9	20.0
		1985	100.0	82.3	9.2	0.3	8.5	40.7	15.7	19.8

Table 7. Labor input coefficients, total of all occupations, 1950-1985

(unit: persons per one billion yen)

	JSIC	Industrial sectors	1950	1955	1960	1965	1970	1975	1980	1985
(1)	01&	Agriculture, forestry, and fisheries	3911.43	2942.28	2373.53	1764.00	1413.01	1025.52	263.20	717.75
(2)	10&	Mining	1804.51	1557.73	1219.50	591.60	231.30	150.26	89.14	79.61
(3)	18	Food processing	298.46	202.31	161.38	153.31	112.34	96.83	85.20	86.78
(4)	20&	Textiles	1043.33	798.83	572.41	473.75	351.53	320.47	285.31	239.11
(5)	22	Lumber and wood products	660.70	685.61	550.27	377.43	240.67	221.26	201.09	n.a.
(6)	23	Furniture and fixtures	857.76	1089.46	942.42	549.20	333.90	273.46	228.11	n.a.
(7)	24	Pulp, paper, and paper products	750.11	582.74	383.98	259.03	145.00	126.84	95.54	82.53
(8)	25	Printing and publishing	2117.36	1363.63	920.76	591.64	327.31	314.15	280.45	n.a.
(9)	29	Leather and leather products	1262.62	1368.99	1113.33	904.41	738.01	541.34	549.27	n.a.
(10)	28	Rubber products	1204.64	305.14	653.59	381.02	294.40	272.72	205.95	n.a.
(11)	26	Chemicals	1012.35	626.32	361.40	210.75	100.08	86.82	57.53	47.71
(12)	27	Petroleum and coal products	208.49	132.54	56.22	23.16	17.37	16.63	14.97	12.66
(13)	30	Nonmetallic mineral products	1138.36	1006.58	707.99	431.10	236.77	230.06	182.45	168.88
(14)	31A	Iron and steel materials	349.39	251.39	179.73	119.72	61.07	50.58	32.36	85.19
(15)	31B	Basic iron and steel products								
(16)	32	Basic nonferrous metal products							50.62	48.23
(17)	33	Fabricated metals	1061.14	1293.48	987.17	556.84	344.3	314.84	234.03	185.32
(18)	34	General machinery	636.38	640.90	383.33	325.85	136.37	124.70	83.27	64.61
(19)	35	Electrical machinery	1495.25	1219.30	451.53	354.91	190.3	156.02	81.46	47.97
(20)	36M	Transport equipment, motor vehicles	2345.67	677.82	352.49	206.12	123.34	101.84	64.32	57.05
(21)	36S	Transport equipment, others	909.99							
(22)	37	Precision instrument	1410.52	938.28	635.92	423.72	262.56	261.08	143.03	110.57
(23)	38&	Other manufacturing	3661.20	1338.41	1453.14	718.52	343.33	298.30	211.16	n.a.
(24)	15	Construction	471.30	622.12	556.09	386.03	242.52	233.96	227.26	225.58
(25)	70	Electric power, gas, and water	536.03	403.64	242.32	184.11	98.31	91.79	81.95	61.62
(26)	40	Wholesale and retail trade	2110.73	2019.20	1966.73	1243.13	703.99	621.30	485.51	463.86
(27)	50&	Finance, insurance, and real estate	340.17	243.49	190.06	189.05	141.64	130.35	125.92	96.57
(28)	50R	Real estate rent	—	—	—	—	—	—	—	—
(29)	60T	Transportation	1330.38	1039.55	764.17	622.42	426.27	252.58	245.97	213.69
(30)	60C	Communication	2388.69	1956.38	1360.52	819.90	458.47	287.27	252.35	219.27
(31)	97	Public administration	—	701.94	563.15	690.79	743.13	453.06	483.34	420.41
(32)	75P	Public services	1074.56	372.24	570.59	431.38	465.14	332.73	361.84	337.35
(33)	75M	Business and personal services	527.09	815.44	1028.45	863.26	549.50	534.94	468.09	460.10
(34)		Office supplies	—	—	—	—	—	—	—	—
(35)		Packing materials	—	—	—	—	—	—	—	—
(36)		Activities not elsewhere classified			9.25	13.93	5.39	15.48	28.63	n.a.
(37)		Total	1371.40	1076.30	761.96	535.31	322.34	264.89	226.93	205.50

Note: For 1985, manufacturing n.e.c. includes the sectors for which data are marked "not available." Production figures for 1985 are from the SNA.

Source: Kimio Uno, <u>Measurement of Services in an Input-Output Framework</u>, 1989.

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[1] Uno [1989], pp.212-213, discusses some of the deficiencies in the current treatment of R&D.

[2] See Statistical Data Bank Project [1990].

[3] According to a syrvey by the Science and Technology Agency of the Japanese government, the gestation period is 3.54 years on the average, with considerable differentials among industrial sectors. See Uno [1989], pp.232-234.

[4] MITI, Survey on Machine Tools Installation.

[5] For details of industrial classification adopted here, see Uno [1989].

[6] Uno [1990], pp.56-66 and pp.195-205.

[7] Quality adjusted deflator for mainframe computers is from Cartwright [1986], and that for industrial robots from Mori [1987]. Sectoral deflators are from Economic Planning Agency.

[8] See Uno [1987], pp.233-256.

[9] See Uno [1989], pp.220-224.

*) A more detailed analysis of this chapter will appear in *Technology, Investment, and Trade* (forthcoming).

CIM in Centrally Planned Economy Countries

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CIM IN CENTRALLY PLANNED ECONOMY COUNTRIES

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Almost all of the centrally planned economy countries--synonym for CMEA countries--currently face political and economic situations never encountered before. This has, of course, many consequences in different areas, including the future diffusion of CIM technologies.

The results of previous analysis by researchers from CMEA countries reached appropriate conclusions, without the possibility to articulate these clearly because of the limited freedom of scientific investigation. All conclusions that tended to deny "the permanent successful development of socialist economies" were discouraged and even punished by different means.

In the area of the diffusion of different CIM technologies, (NC, I.R., CAD/CAM, FMS) the results of our analysis of their penetration levels has shown some irregularities compared with classical diffusion processes usually modeled by means of a learning curve.

For example, the analysis of the penetration of NC machines into the Czechoslovak metalworking industry (Mudra, 1989) indicates that the apparent diffusion process is almost exponential.

Similarly, Maly and Záruba (1988) analyzed the penetration of industrial robots into the Czechoslovak metalworking and electrotechnical industries and again there was no classical S-curve but essentially an exponential development. Authors from other socialist countries (Dudnikov, 1987) came to similar conclusions.

The likely explanation is that development in centrally planned countries was always presumed to follow the "plan". The "plan", in turn, is based on the rule of linear permanent constant yearly increases of all the planned parameters. If the increase is higher the development is exponential.

The main reason for this is evident: total absence of market conditions, absence of labor and capital goods markets and other attributes. But what are the driving forces behind the exponential model of the CIM technologies penetration? This rhetorical question can be answered from a political perspective. The development of different forms of automation was one of the arguments of political leaders of the previous regime to convince their own people and the world that centrally planned economics is an efficient system--not merely comparable, but from some point of view superior to the market economy system. The case of "rapid penetration of I.R. in GDR", where all very simple manipulators were included in robot statistics is one of the examples of political influence on that topic.

However, the main problem for the future arises from the fact that the development of CIM technologies in CMEA countries had not had any economic basis. The permanent increase of these technologies was formal and not in the least connected with the economic justification for CIM technology in real factories. Of course, some justification was carried out. But in the absence of real prices, exchangeable financial instruments and other attributes of a market economy, it was formalistic fiction. Managers of factories fulfilled their targets, quotas, if possible, or pretended to do so if not. But there was little economic motivation for technological innovation in the production process if it did not have an immediate impact on output.

The analysis of strategic goals and main driving forces behind FMS adoption (Maly, 1990) clearly reveals the near absence of dominant goals in CMEA countries. In market economies the average high priority factors (4 and 5 on a scale of 1 to 5), in companies installing FMS was 4.9 in centrally planned economy companies (such as Czechoslovakia) it was as low as 2.5. Essentially this reveals a total lack of dominant goals in FMS companies in centrally planned economies. The most logical explanation of this phenomenon is that the impetus to adopt the system did not come from inside the company, and it was not implemented by decision-makers of these companies. It came from a central governmental body whose criteria were often unclear or even unknown to the company management. Presumably, the implementation of an FMS was seen as part of the state plan. As such it had to be fulfilled, frequently without any incentive for the company's top or middle management to take a strong interest.

Summarizing the above mentioned arguments we suggest the hypothesis that the diffusion process of CIM technologies in CMEA countries, so far, has been only a poor imitation of the diffusion processes of the same technologies in market economy countries. It has not been justified by real economic cost/benefit criteria.

Accepting this hypothesis, we immediately face the very interesting question: what will be the future evolution of the diffusion process of CIM technologies in CMEA countries, as they transform their economies from centrally planned to market-driven? The most typical examples could be Hungary, Poland, Czechoslovakia, the GDR, and perhaps Bulgaria.

We can approach the problem by means of a scenario method (see Figure 1).

We start from the actual situation that now exists in different CIM technologies and different countries around the years 1989 - 1990. It is obvious that the level is different in different technologies and different countries. One level labelled (1) on the graph is depicted for the sake of simplicity.

The "transition gap" represents the time of transition from a centrally planned to a market economy. We expect that new investment activity, not only in the case of CIM technologies, will be very low during the period of the "transition gap". This occurred in the cases of Poland and Hungary, where investment activity in CIM during the year 1989 was negligible.

The length of the period may depend on many political, economic, legislative, international and other factors. We can assume that in the most favorable case, corresponding to the shortest "transition gap" is likely to be the GDR, because of its forthcoming unification with West Germany.

After re-establishing stability with market forces operating there the developments might follow one of he following basic scenarios, for different CMEA countries:

Scenario No. 1: the traditional S-curve starts immediately in the "growing phase". It will be possible when the economy obtains strong support from other strong economies (such as the GDR from FRG), or the attractive conditions for foreign capital which might be created (joint ventures, limited companies attractive to foreign shareholders). In such a stage, the majority of the companies are rapidly privatized, e.g., perhaps in countries such as Hungary.

Scenario No. 2: the S-curve starts reverts to the "embryonic phase". This scenario corresponds to the situation that the privatization of the economy is based mainly on national resources and foreign entrepreneurs are hesitating because of the nuclear legal conditions for private business, perhaps Czechoslovakia, or they are afraid of the low efficiency of the economy, perhaps Poland, and the ratio of state owned companies is relatively high.

Scenario No. 3: the S-curve starts in a "maturity phase". This might correspond to a case where, in the course of the next few years, the government decides to restructure the economy slowly and to change the orientation to small companies, based on information technology, services, tourism and agriculture, maybe Hungary?

Scenario No. 4: the S-curve starts in the final or "postmaturity phase". In that case the government undertakes to compensate for previous over-emphasis on industry and make basic decisions concerning restructuring of the national economy. This might imply reorientation to emphasize investments in other branches of the economy such as agriculture and tourism, perhaps Bulgaria?

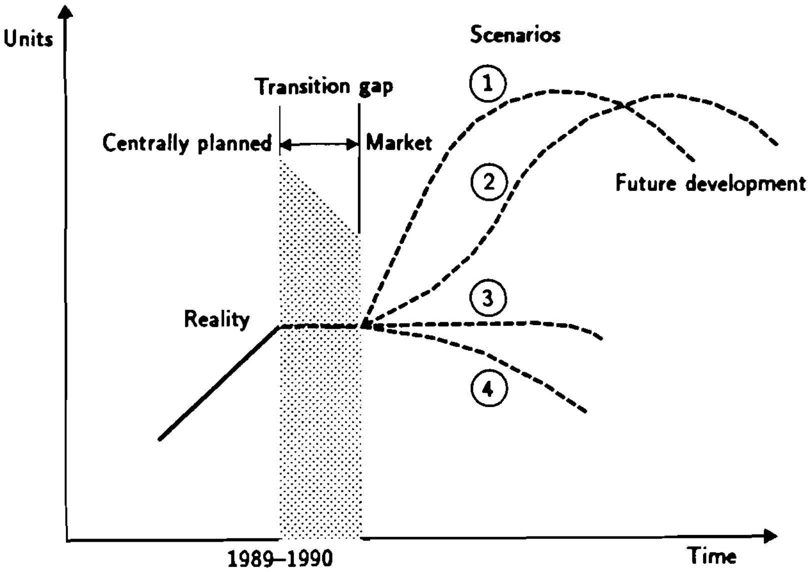

Figure 1. Future evolution scenarios.

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High Technics Diffusion Models and a Synthetic Measure of the Industrial Modernity

by

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I. Introduction

It will not be too much to say that scientific and technological progress are the main driving force behind economic development. At the same time every new barrier to science and technology stimulates and accelerates still better solutions. There is a feedback relation between the level of science and technology and socio-economic development. Recent scientific discoveries have offered the economy technologies which enable to manufacture goods at still lower levels of energy, raw-material, resource and labour consumption.Therefore more resources could be allocated in the services, development of sciece and innovation. It could be said that the old homo-faber is gradually giving way to homo-doctus, while the sheer physical and organisational job is beeing done increasingly by ever more sophisticated machines.

With the rapid flow of information these days new discoveries and inventions are being disseminated very quickly creating opportunities even for countries with a relatively low scientific and technological potential.

At the same time we can observe a considerable shortening of the time-span from the actual new technological or scientific breakthrou to the moment it is given to the general public. In other words the transmission from science to the technology and to the market are nearly instanteneous. One reason is, on the one hand, high technological countries and, on the other, competition or maybe even a race among the leading scientific centers working on the cutting edge of science and technology today.

Research and development require substantial outlavs and their concentration. Actual implementation of new technologies is also costly. Of course the effects of new inventions soon pay back through the elimination of the most costly factor of production /under market economy/ - labour, and in consequence facilitate greater effectiveness, greater output and mass production at ever lower cost. What is more new products offer better quality and reliability. So it could be said that the high outlays on research and development facilitate and stimulate the manufacture of high-quality goods and pay off in a relatively short time.

While science and technological progress are without doubt the main driving force of socio-economic development, the interest in methods of analyzing technological progess, and especially the diffusion of modern technologies is an undisputable fact. Such research is conducted all over the world in research centres in many countries.

As regards Poland, the diffusion of modern technologies is a rather slow process due to the recent economic and system and chronic economic crisis. Nonetheless transformation in our economic sytem offer hopes for an acceleration of technological diffusion. Monitoring these processes is very important because it may bring clues to growth trends in Poland.

Therefore the Research Centre for Economic and Statistical Studies of Central Statistical Office and Polish Academy of Sciences is currently conducting research work on the models of diffusion of modern technical equipment. This paper presents methodological assesment of diffusion models results of estimation for selected modern technical products.

The paper also presents the assessment of the degree of technical modernity an individual branches of industry in Poland as an illustration of the multi-dimensional comparative analysis and its application in the construction of syntetic measures of technical advancement of industries.

2. Models of Diffusion of Technical Progress

Usually diffusion models in experimental sciences employ the logistic curve or Gompertz curve to describe the spread of an epidemics or diffusion of substances until a certain level of saturation is achieved.

Let us remind the equation of the logistic curve:

$$y_t = \frac{k}{1 + b\, e^{-at}} \qquad /1/$$

where:

y_t - value of logistic function at point t,

e - base of natural logarithms,

t - time,

a,b,k - parametres of the logistic function /value k is the level of saturation/ which are positive. Let us examine the properties of the curve.

The derivative of the logistic function equals

$$y' = \frac{a}{k} y/k-y/ \qquad /2/$$

Remembering that for every $t \geq 0$ we have $0 < y < k$, and that parameters a and k are positiv, the first derivative of the logistic function is always positive, therefore the function is continuously growing. The rate of growth of the logistic curve is - as can be seen from /2/ proportional to the value k and to the difference between the level of saturation k and the level y_t.

Calculating the logarythmic derivative defining the rate of growth of the function have

$$\frac{y'}{y} = a /1 - \frac{y}{k}/ \qquad /3/$$

It follows that parameter a could be interpreted as a kind of potential growth rate because for very small values of y the second component in near to nil and the rate of growth is defined by a.

The second derivative of the logistic function equals

$$y'' = {}^{2} /k - 2y/ \frac{y /k - y/}{k^2} \qquad /4/$$

and the sign of the second derivative tells whether it is convex or concave, or in other words informs about the speed of growth. At the point, where the curve changes from convex to concave the second derivative equals zero.
The coordinates of the point of inflection of the logistic curve are, respectively $t = \frac{1}{2} \log_e b$ and $y = \frac{1}{2} k$, which means that the logistic function could be divided into two intervals:

1/ for every t from the interval $0 < t < \frac{1}{2} \log_e b$ and respectively, $\frac{k}{1 + b} \leqslant y < \frac{1}{2} k$ we have $y'' > 0$, so the function within this interval describes a rising growth rate, 2/ for every t from the interval $\frac{1}{2}\log_e b < t < \infty$, and respectively $\frac{1}{2}k < y < k$ we have $y'' < 0$, so the function within this interval describes a falling growth rate.

The logistic function, besides the above properties - which correspond to the real processes of diffusion - has also one more property - not necessarily always corresponding to reality: it is its symmetry with respect to a straight cutting through the point of inflection and the normal to the time-axis. Growth is initially slow and accelerates until reaching the inflection then it falls. The whole process of a falling growth rate is analogous to that of increase of growth rate. Therefore other S-shaped functions were examined to better describe the diffusion of e.g., durable goods. A.B. Bain /1964/ described the rate of growth of the number of tv sets with the following differential equation:

$$\frac{dq}{dt} = \frac{\alpha}{t\sqrt{2\pi\sigma^2}} \exp\left\{ - \frac{1}{2\sigma^2}\left[\log t - \mu\right]\right\} \qquad /5/$$

where:

q is the ifaction of households with tv sets. The graph of the distribution curve of the logarithmic-normal distribution plays in this case only the role of a function reflecting the diffusion in time and is not a proper distribution curve. Parameters μ and σ then become parameters describing the growth of resources, and μ reflects the rate of growth. We could try and identify closer the parameters and say that the inverse of μ is the measure of growth of resources. With σ const. the higher the value of μ or the smaller the value $\frac{1}{\mu}$ the more time is needed to increase resources by a definite increment. At the same time for a given μ along with the growth of parameter σ , there is also increase of time necessary to reach growth from a certain level below 50.0 per cent of saturation up to an analogous level above 50.0 per cent.

Considering that equation /5/ is a differential equation of the distribution curve of the logarithmic-normal distribution the level of saturation $\alpha = 1$ and if μ and σ are constant then the growth curve is a logarithmic-normal curve. But when parameters change then the growth of resources depends of the actual values of parameters and its graphis representation is not a single curve but a set of segments of logarithmic-normal curves.

Assuming that the parameters μ and σ remain constant we could calculate the time that passes from the beginning of growth till the moment when the level q_t of resources is reached.

It is

$$t = \exp /\mu + \sigma y/ \qquad /6/$$

where:

$$y = \frac{\log/t/ - \mu}{\sigma} \qquad /7/$$

Asymmetry of the logarithmic-normal curve better describes the real process of growth. Therefore it could be expected that theoretical and real-life values of resources will lie closer.

The diffusion models using the logistic curve and logarithmic-normal curve could well be illustrated on the example of the diffusion of numerically operated machine-tools. See graph 1.

3. The Logistic Funtion with Estimated Level of Saturation

The results of estimation of parameters of the logistic function are presented in the form of estimations of the parameters of equation /12/ and a graph of theoretical and observed values of diffusion. For numeric machine-tools the results were very good indeed. The model explains 92.0 per cent of the change in the growth of the number of those machine-tools, while the estimations from zero already at 1% level of significance.

Recalling that what we are finding directly are not assessments of the parameters a,b and k but their functions we have:

a^{xx} = 0.451899, k = 3436.49 and b = 38.77.

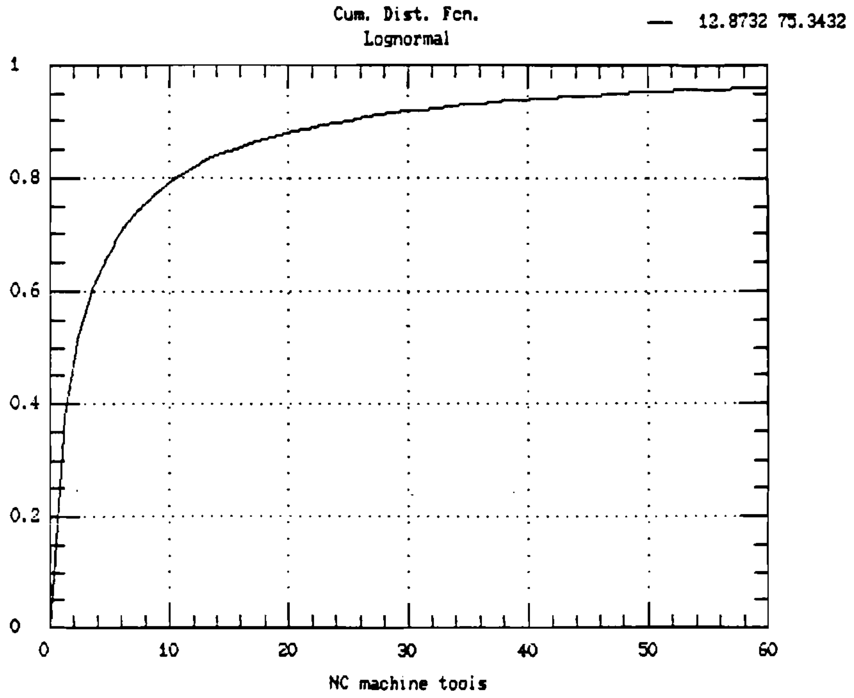
Eventually the logistic function describing the growth of the number of numeric machine-tools could be presented in the following formula

$$Y_{1t} = \frac{3436,46}{1 + 38,77\ e^{-0,4519t}} \qquad /8/$$

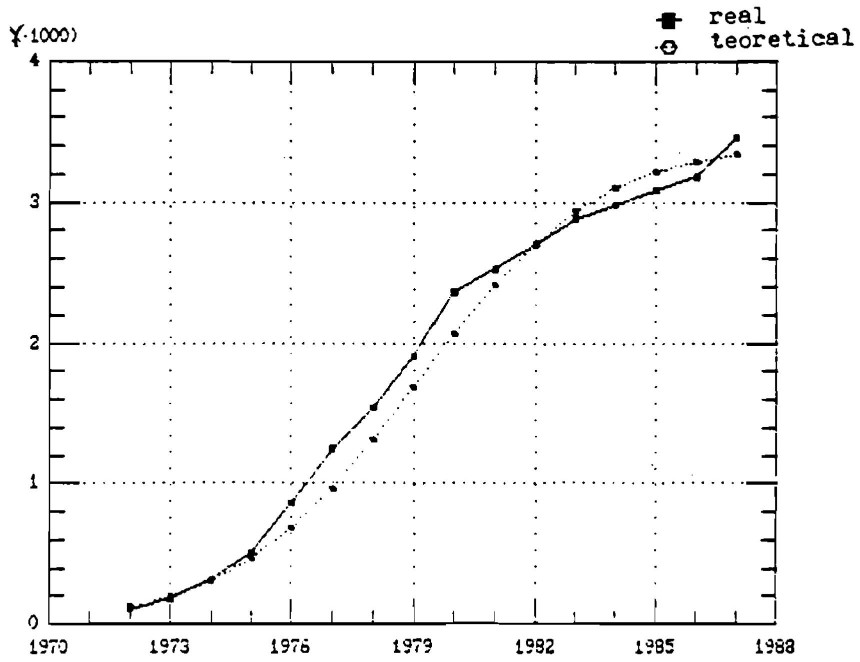
Graph 2 presents the observed numbers of numeric machine-tools and the logistic function described by equation /8/.

As you will see the last observed value exceed the level of saturation. The point of inflection is clearly marked in 1986 and then there follows an increase. this could mean the beginning of a more dynamic rate of growth of numeric machine tools and

Graph 1



Graph 2



Numeric machine tools

a change of the shape of the curve. Hence it would be interesting to estimate the parameters of the logistic curve with a pre-set level of saturation.

It is obvious that the level of saturation moves upwards depending on favourable economic conditions, specifically in this example where we have taken absolute values. It is not possible to relate the absolute levels of the number of numeric machine-tools to the overall number of these machines if only because of the substitution between aggregates of different types of machine tools. At the same time forecasting needs suggest that the saturation level be somewhat more distant from the last value observed. Therefore it is worthwhile to estimate the parameters of the logistic function with an a priori level of saturation or a pre-set value of parameter k.

Transforming the logistic function in such a way as to have the parameter k on the left side of the equation /1/ we have,

$$\frac{k}{y_t} - 1 = be^{-at} \qquad /9/$$

and an estimation equation takes the following form:

$$\ln\left(\frac{k}{y_t} - 1\right) = \ln b - at \qquad /10/$$

where:

the endogenous variable is a natural logarithm of $\frac{k}{y_t} - 1$
and the estimated parameters are ln b and parameter -a.

It is evident that an a priori level of saturation should be preceded by a thorough analysis by specialists or by analogy with other more advanced countries. The above example is intended only as an illustration.

Two alternative levels of saturation were adopted: 5,000 and 6,000 numeric machine tools respectively. The estimations proved quite satisfactory. They very distinctly from zero value and the two alternative models account for 91.0 per cent of variability $\ln \frac{k}{y} - 1$

The models could be presented in the following way:

$$y_{1t} = \frac{5000}{1 + 28,134\, e^{-0,2934t}} \qquad /11/$$

or

$$y_{1t} = \frac{6000}{1 + 31,307\, e^{-0,2714t}} \qquad /12/$$

For the logistic curve /11/ the level of resources reached the inflection point between 1982 and 1983. The growth rate will then be slowly decreasing. The volume of resources will approach the level of saturation after eleven years.

As regards the curve described by equation /12/ the resources exceeded the inflection in 1984 and it could be expected that after thirteen years the volume of resources will be near saturation level.

The above example of logistic curves with differing levels of saturation corresponds with the real diffusion of technology when the growth follows a set of curves with varying levels of saturation depending on price reductions on those machines and in accordance with the learning process.

4. Synthetic Measure of Modernity in Industrial Branches

The analysis of diffusion on a higher level of aggregation -on macro-scale - poses numerous problems. A description of how.modern a given branch of industry is, requires a large number of indicators quite often impossible to reduce to value categories. This and also multidimensionality of the effects of technical progress create quite naturally a need to apply taxonometric methods.

We know that a disadvantages of all taxonometric methods is the arbitary selection of indicators characterizing the objects to be compared. However, when such a selection is done on the basis of a careful analysis or expert opinions then we could find adequate synthetic measures of technical modernity in individual branches of industry.

If we treat the branches of industry as objects described by some numbers of the characteristics, we get a matrix of observations

$$X = \begin{bmatrix} x_{11} \cdots\cdots\cdots\cdots x_{1n} \\ \cdots\cdots\cdots\cdots\cdots \\ \cdots\cdots\cdots\cdots\cdots \\ x_{m1} \cdots\cdots\cdots\cdots x_{mn} \end{bmatrix} \qquad /13/$$

where x_{ij} is the value of j-th characteristic in i-th branch, $/i=1,2,\ldots m/$, $/j=1,2,\ldots n/$. /Usually this characteristics are used after standardization/.

We could expand the range of characteristics in matrix X by, for instance, outlays for individual branches of industry and effects. Let us assume that first k of characteristics describe outlays and the $n-k$ reflect the effects reached. Then the pattern becomes a hypothetical unit described by vector x_0

$$x_0 = \left[x_{o1},\ x_{02},\ldots\ldots x_{0k}, x_{o\ k+1},\ldots\ldots, x_{0n} \right] \qquad /14/$$

whose elements are minimal values from the first k columns and maximal elements from the next n-k columns:

$$x_{oj} = \min x_{ij} \quad \text{for } j=1,2,\ldots\ldots,k$$
$$x_{oj} = \max x_{ij} \quad \text{for } j=k+1,\ldots\ldots,n \qquad /15/$$

Next, we calculate the distances between the branches of industry, and the hypothetical pattern defined in a n-dimensional space of characteristics, and get the following vector

$$d_0 = \left[d_{10},\ldots,d_{i0},\ldots,d_{m0}\right] \qquad /16/$$

The measure of the distance of the vector could be defined by a following equation:

$$d_{i0} = \left[\sum_{j=1}^{n} /x_{ij} - x_{oj}/^2\right]^{1/2} \qquad i = 1,\ldots\ldots,m \qquad /17/$$

or another equation:

$$d_{i0} = \frac{\sum_{j=1}^{n} \left|x_{ij} - x_{oj}\right|}{m} \qquad i = 1,\ldots\ldots,m \qquad /18/$$

The distance from the pattern is a synthetic measure describing the effects of each branch of industry..Calculating the following

$$d_i = \left(1 - \frac{d_{i0}}{d_0}\right) \cdot 100 \qquad i=1,\ldots\ldots,m \qquad /19/$$

where $d_0 = \bar{d} + 2\,S_0$,

$$\bar{d}_{i0} = \frac{1}{m}\sum_{i=1}^{m} d_{i0} \quad \text{and} \quad S_o = {\frac{1}{m}\sum_{i=1}^{m} /d_{i0} - \bar{d}_{i0}/^2}^{1/2}$$

we obtain the measure from interval $(0\ ,1)$.

The results presented here are meant to be not only an example of the application of one of multi-dimensional methods of comparative analysi /the so called distance from the pattern, Hellwig/1968// to the assessment of the modernity and introduction of technical progress, but they can also be seen as an illustration of an analysis of real changes which took place in industry in 1985-1988.

The set of variables describes the succeding aspects of production processes in individual branches of industry. The modernity of the fixed assets has been defined as follows:

1/ number of automated means of production,
2/ number of computerized means of production,
3/ number of multi-purpose machine centers,
4/ number of robots,
5/ number of computers.

The modernity of technologies is described by two variables 6 and 7, which are the percentage shares of modern technologies in production overall. Let us remember that these are special technologies employed in and specific for various branches of industry.

The effects of implementation of technical progress:

8/ the share of savings achived due to technical progress in productio
9/ total effects of technical progress as a share /percentage/ in total value of production.

Quality of production:

10/ the percentage share of new and modernized goods in production
11/ the losses due to inferior quality of production.

Pollution of the natural environment measured by:

12/ volume of industrial sewage /in hectoliters/,
13/ emission of pollutants /in thousands of tons/,
14/ volume of industrial waste particulary harmful to the environment.

Energy consumption:

15/ Energy consumption on thousands of zloties of production, in kilowatthours.

It is obvious that the initial 10 variables are stimulants and their higher values represent more modern production. The remaining variables are destimulants, which means that they should be minimized.

The taxonometric method of the distance from pattern was applied to ordering the set of branches for the years 1985 and 1988. Table 1 presents the distances in decreasing order. The position of the two closest to the pattern branches of industry did not change in exmined period. These are the electronic, electrical engineering, and transport industries. At the same time the engineering industry fell in 1988 from third position to fifth.

The fuel and power group of industries occupies the positions farthest removed from the pattern. Also distant from the pattern are the "light industries" but within that group textile industry moved upwards in 1988, from 12th place to 6th place due to automation of production lines and computerization. Clothing and leather industries are also rather distant from the pattern due to low level of automation.

Other industries positined far from the pattern include: non-ferrous metals,,pottery and china, paper, and building materials. This is not a homogenous group and so various reasons determined their position from the pattern. For example, pottery and china production is little mechanized and using traditional methods of production. Non-ferrous metals product, paper, and building materials belong to a group of industries which cause the heaviest pollution of the natural environment.

Closer to the pattern we have industries from electrical engineering and chemical group, probably due to considerable automation of production.

Table 1. The order of the branches of industry according to a decreasing distance from the pattern.

No.	1985		1988	
	vector of distance	number of object	vector of distance	number of object
1	13.98419	3	13.74474	3
2	12.12069	18	11.58912	5
3	11.89706	14	11.57988	18
4	11.5967	5	11.38836	14
5	11.54745	2	11.14499	1
6	11.52359	16	10.97548	19
7	11.49168	19	10.9392	2
8	11.46208	18	10.80997	16
9	11.2245	17	10.05069	12
10	10.89974	13	10.0234	15
11	10.70916	12	9.996408	20
12	10.44478	20	9.981841	4
13	10.33067	15	9.62008	6
14	10.22762	4	9.488176	8
15	10.00097	6	9.197817	17
16	9.882481	8	9.010157	7
17	9.775663	11	9.003865	11
18	9.118298	7	8.697492	13
19	8.906812	9	8.575548	9
20	7.177617	10	6.309929	10

Power production is harmful for the environment and that is why it occupies a distant position from the pattern. We could ask whether environment pollution should be taken into account in completing the set of characteristics. The answer is obviously positive since modern technologies considerably eliminate the harmful effects of industrial productior even those which out of its nature pollute environment.

Relatively homogenous is the group of industries that are situated the closest to the pattern because these are characterized by the highest degree of mechanization and are relatively less harmful for the environment. These include : electronics and electrcal engineering, transport equipment, and engineering.

In 1988, with the exeption for the extremal positions i.e., the closest and farthest from the pattern - the ordering of the branches changed. The changes could be seen better in Table 2 which shows the numbers of positions each industry occupied for the years 1985 and 1988. Moreever the last column shows the change of position and the direction /upwards or downwards/. Zero means no change.

The industries which moved farther away from the pattern in 1988 include the following: coal, metallurgic, non-ferrous metals, precision, building materials, wood, leather, and food. Of course a downard move corresponds to a worsening situati in a given industry with regard to modernisation. Yet these unfavourable changes are not too radical as the fall is not greater usually by three places below the initial rank.

The most radical changes - as was already mentioned - concern the textile industry, which moved upwards by six places. Considering the fact that in 1988 there were fifteen computerized production lines, while in 1985 there were none such lines, the upward leap seems only natural. Similarly, seventeen new computerized lines in glass industry and also improvement of other indices-stimulants helped the industry to reach

Table 2. The ranking of industries according to the distance from the patern in 1985 and 1988.

No	Branch of industry	Ranking according to distance		Change of position 88/85
		1985	1988	
1	Coal	13	16	-3
2	Fuel	16	13	+3
3	Power	20	20	0
4	Steel	7	9	-2
5	Non-ferrous metals	17	19	-2
6	Metallurgia	6	6	0
7	Engineering	3	5	-2
8	Precision	5	7	-2
9	Transport	2	2	0
10	Electrical engineering and electronic	1	1	0
11	Chemical	4	4	0
12	Building materials	10	11	-1
13	Glass	11	3	+8
14	Pottery and China	18	17	+1
15	Wood	8	11	-3
16	Paper	15	13	+2
17	Textile	12	6	+6
18	Clothing	19	18	+1
19	Leather	14	17	-3
20	Food	9	10	-1

a place close to the pattern from 11th in 1985 up to 3rd in 1988. The other industries which have recorded an improvement on the list include: fuel, china, wood, and clothing.Several industries remained stable: power, transport, electrics and electronics.

It is also worthwhile to compare the measures of distance from the pattern through relating each distance to an average distance calculated for all branches. Table 3 presents the results according to the mearure d_0 /see /19//. This measure is from 0-1 interval and therefore it is easy to asses the position of each industry on the scale.

In 1985 the electrical and electroncs industry visibly outstanded the other branches, reaching nearly a half of the values on the scale of modernity and sustained that distance in 1988. Over one third on the scale was reached in 1985 by the following industries: transport equipment, and engineering. These were joined in 1988 by glass, chemical and textile industries. In 1985, between the values 0.2 and 0.3 there were the following industries: chemical, precision instruments, metallurgic, steel, wood, food, and building materials. In 1988, they were joined by textile and glass industries.

Below 0.2 but higher than 0.11 we had in 1985 the following industries: glass, textile, coal, leather, paper, fuel, non-ferrous metals and china. In 1988 glass and textile industries left the group and moved upwards owing to modern production lines.

Assesing the results of applying a taxonometric method to estimate the measure of modernity for industrial branches we could draw the following conclusions, regarding both - the method itself and the results.

- The Hellwig method /distance from the pattern/ could be successfully applied to find out the degree of modernity of industries and to examine the changes in time.

Table 3. Measure of modernity of industries

Ranking according to distance from pattern	1985		1988	
	measure of modernity	object number	measure of modernity	object number
1	.4679914	10	.4764531	10
2	.3398225	9	.3407125	9
3	.3241471	7	.3313374	13
4	.2754228	11	.3077834	11
5	.2675055	8	.3072997	7
6	.2587231	6	.2928724	17
7	.2419235	4	.2705497	8
8	.2342854	15	.2604089	6
9	.2258273	20	.2325967	4
10	.2062314	12	.2314769	20
11	.192106	13	.2294015	15
12	.1680347	17	.227304	12
13	.150425	1	.1689301	16
14	.1482309	19	.1589948	2
15	.1458657	16	.1562061	19
16	.1440972	2	.1431736	1
17	.1404465	5	.1244634	14
18	.1181836	14	.1097393	18
19	.1016082	18	.1090295	5
20	-3.651548E-02	3	-5.669511E-02	3

- This method is not particulary sensitive to changes in the set of variables selected for examination, as is well testified when one of variables was removed.
- The results of arranging the industries according to their distance from the pattern allow us to distinguish the following groups:

1.Industries closest to the pattern characterized by a relatively high level of mechanisation and relatively little harmful for the environment /electronics and electrical engineering,transport equipment, and engineering/.

2.Industries farthest removed from the pattern characterized by relatively high input of labour and highly harmful for the environment /fuels and power, steel, a part of light industries/.

3.Industries at considerable distance from the pattern comprising non-ferrous metalurgy, china, paper, building materials. It is non-homogenous group because china and also partly building materials industries are characterized by traditional technologies. The remaining industries in the group are harmful for the environment.

- Changes that have occurred in the ordering of industries between 1985 and 1988 concern first of all the glass and textile industries - upward shift by 8 and 6 places due to increased automation, and introducing new products. ne number of other branches increased in 1988 the distance from the pattern.

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Economic Justification of FMS Introduction

by

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Introduction

This paper attempts some methodological insights and recommendations for a precise and justified analysis on the implementation of flexible manufacturing systems (FMS), investment credits, the variants to accomplish FM production targets, and other related undertakings. The study takes as its starting point the economic efficiency of adopting FM systems. By way of example, estimates of data demonstrating important efficiency indicators and the impact of the factors of time and economic risk are used.

Starting Points for Defining the Economic Efficiency of Adopting FM Systems

This section discusses the methodological grounds for defining the economic benefits of introducing FM systems. It suggests one main criteria as an indicator with a system of additional indicators, and emphasizes the need for paying special attention to the effects of the property of flexibility. There is also an analysis of the approach for comparing FM systems and conventional technological projects. Finally, it sums up the principal minimum conditions for the acceptability of FM projects.

Large initial costs and a number of post-installation effects require that FM investment decision-making should account for the economic processes taking place across the whole economic life of the project. By economic life we mean the time-span for both the construction and introduction of the project, as well as the time of its use and maintenance equal to the depreciation time limit of basic machinery and equipment.

The principal indicator for the economic efficiency of implementing FMS is the return time of the capital costs of the investment. Accounting for the time factor (the advantages and expediency of this method are discussed in Section Two), the return time is defined as the time needed by the present algebraic total of accumulated annual profits (losses) to cover corrected capital costs, that is,

$$\sum_{t=y}^{T}(P_{pr})_t = (K), \tag{1}$$

where T is the pay-back time in years. This period begins in the year (y), when the project comes into operation. $(P_{pr})_t$ is the present value of the balance profit for the pay-back period. Brackets mark present values, i.e. multiplied by the updating factor. (See formula 4.) (K) is the sum total of updated capital costs for the project.

The efficiency criteria assumes different values at the two major levels of FMS decision-making, the level of a single economic organization and that of the whole economy. The estimation of efficiency on each management level proceeds from the different values of capital costs and effects (in related productions), in either the whole economy or a given economic unit. This paper mainly concerns economic processes at the enterprise level.

The economic effect of FMS implementation derives mainly from:

1. the high degree of production cooperation which reduces the prime cost of components compared to the estimated benefits of the previous status quo (saving of labor, materials, depreciation, etc.);
2. saving of interest for circulating assets credits due to shorter production cycles and faster turnover of circulating assets;
3. the economic estimate of social effects;
4. the economic benefit of better quality when it can be estimated in quantitative terms;

5. saving of hard currency due to lower costs; and
6. the economic effect of the FMS's property of flexibility.

Flexibility deserves special consideration. It is flexibility that brings forth higher cooperation with FM systems. Its quantitative implications are also being increasingly recognized in practice because they provide particularly relevant opportunities for enterprises to respond to today's competition by shorter economic life-cycles and polivariant products.

The effect of flexibility can be estimated by means of:

(a) the number of end components machined by FMS for a given period,

(b) the system's flexibility co-efficient equal to:

$$K_f = Ppr/FA.100 \qquad (2)$$

K_f is the FMS flexibility co-efficient.

P_{pr} is the production program for a given period.

FA is the mass of fixed assets at their initial value.

The quantitative value of flexibility co-efficient is conditioned further by the decision-making level and the long-term strategy of the enterprise (respectively, the state).

The capital costs of basic investment of FMS comprise:

- direct capital investment in constructing all sub-systems
- indirect capital investment in technologically related enterprises (when allocating expenditures for the whole economy)
- the value of available fixed assets (in residue or recovered terms) envisaged to be used for the FMS project
- the difference between the remaining value of available fixed assets that are to be liquidated and the income derived from their realization
- the value of regularized circulating assets
- the value of technological documents, know-how, etc.

The system of additional indicators characterizing the economic efficiency of FMS investment projects includes:

A. Indicators for the economic efficiency of resource utilization (in kind and cash)

1. The economic efficiency of production assets calculated in terms of their profitability
2. The economic efficiency of labor resources use measures in conditional saving of personnel
3. The economic efficiency of utilizing raw and prime materials estimated in saved material expenses for a given kind of output
4. The economic efficiency of using less energy (lighting, heating, machine power, etc.)
5. The economic efficiency of initial capital (or current) currency costs estimated in respect to their profitability
6. Net currency effect defined as the difference between present export currency returns and updated capital cost, and current production costs in foreign currency and Levs for the whole economic life of the project.

B. Specific techno-economic indicators:

- labor productivity in kind
- productivity per unit of area
- quality of output

C. Economic estimates of the social effects such as, saved payments for temporal disability, labor safety, social consumption funds, and other factors typical for a given project.

D. Economic estimate of competitivity through indicators like:

- export profitability vis-á-vis production assets
- export profitability vis-á-vis f.o.b. prime costs
- export currency efficiency

The FMS option should be justified by its advantages as compared with existing production organization. Here we come across the question of the basis of comparison.

The advantages of better work organization are proved best by comparing the cost-and effect characteristics of FMSs and conventional machinery. The two most possible variants are:

1. A comparison of the indicators for FMS and for unautomated manufacturing with new equipment of the already installed technological type
2. A comparison of the indicators for installed technology provided with CNC devices and for FMS

Naturally, the possibility for appropriate choice is greater in the case of having several variants of the enterprise's strategy to move on to comprehensive and flexible automation.

The basis of comparison should exclude automated production lines used usually for large series, since FMSs are aimed to improve the organization of small and medium series of polinomenclature products.

The most appropriate comparative analysis is to compare FMS costs and effects with these of CNC conventional technologies. This is the best way of demonstrating the advantage of FMSs' higher degree of work cooperation in manufacturing.

Investment in FMS projects can go ahead provided it meets the following minimum conditions for acceptability:

1. Its expected present balance profit should cover the updated capital costs at least once within the economic life of the project, that is:

   $$E_{bal} = \sum_{t=y}^{T}(P_{pr})t/(K) > 1, \qquad (3)$$

   where E_{bal} is co-efficient of efficiency, (K) is the total value of updated capital costs.

   The greater the number of pay-backs, the better the investment project.

2. The balance profit of a normal production year should cover all the costs and payments envisaged in the scheme of profit-and-income formation and distribution.
3. Its specific indicators should correspond to the results of leading manufacturers. Comparisons go along basic technological parameters and are made in cases of well-proven comparability.

4. The project should be efficient even in strained production and economic conditions.
5. Should ensure flexibility equal to or greater than the flexibility strategically fixed for a given economic unit or, respectively, the state.
6. The project should be competitive.

Estimate of the Economic Results and Effects of the Installation of FMS

This section examines the characteristics of the FMS introduction process, and suggests some procedures for efficiency estimation techniques involving assessment of the advantages of this new production system. Based on model data for a FMS project, it assesses the influence of the time and the economic risk factors upon a number of major efficiency indicators (pay-back time, profitability, net profitability), and compares the results of different assessment techniques.

The problems faced when estimating the efficiency of FMS projects derive mainly from the inability of possible users to undersand all the advantages of new production organizations based on the achievements of the microchip revolution, such as, more rapid changes in design, and achieving faster installation and on-line targets. There is also a sporadic use of the various techniques for the estimation of cost–effect changes due to:

- Different time continuums for design, construction, and achieving expected manufacturing capacities in projects with and without FMS.
- The uneven distribution in time of capital outlay for fixed assets, expenses for pooling circulating assets, the delivery moments of different outputs, current production costs (assignments, services) and fixed capital repair and maintenance costs.

The best way to cope with these problems is to resort to the dynamics technique, that is, to estimate the influence of the time factor. In practical terms, this relates to calculating the value of what is called "inner-company and national economic co-efficients of updating". It gives a quantitative expression of the value of time saved by increased turnover and circulation of production resources (faster design, rapid construction, the introduction of new facilities, just-in-time production renewal), or of the loss effect due to lower turnover intensity (slow design, construction, retarded start of operation and long and unjustified periods of sticking to available production capacities).

We now compare the values of some major efficiency indicators (the pay-back time, profitability, and net profitability), obtained through the conventional and the dynamic techniques. The data for the FMS project is used by way of example.

Assuming that the whole operation period is 10 years and construction takes two years (i.e., the economic life is equal to 12 years), and the inner-company (updating) co-efficient is 10 percent.

The updating factor (f) is defined as

$$f = \frac{1}{(1+r)^n} \tag{4}$$

r is the updating co-efficient (equal here to 10%), n are the years after the first investment.

The present values of capital costs of basic investment (Table 1, line 5), of balance profit (line 6) and net profit (line 7) are the product of their nominal values in respective years (lines 1 and 2), and the updating factor (line 4). Their magnitude describes the present value of future capital costs and profits/losses from the viewpoint of the FMS decision-making year and its efficiency estimates. The different assessment of these indicators with and without the time factor is demonstrated in Figures 1–3.

Table 1. Initial data for estimating the economic efficiency of FM introduction.

	1984	1985	1986	1987	1988
Capital costs '000 Levs	5000	15000	8580	1452	1532
Present value -/-	5000	13635	7087	1090	1046
	1986	1988	1990	1992	1994
Balance profit -/-	18200	21077	25389	30743	34000
Present value -/-	15033	14396	13710	14375	13124
	1986	1988	1990	1992	1994
Net profit -/-	4525	5791	6417	7827	8700
Present value -/-	3738	3955	3619	3655	3358

The pay-back time for the FMS project (Table 1, lines 5 and 6), calculated by formula 1 is 1.9 years (approximately, 23 months). The pay-back time calculated without the influence of the time factor is 0.8 years (about 10 months). This is the quotient of the nominal capital costs total and the nominal profit of FMS in a normal production year with maximum loading of equipment. The difference in pay-back times with and without the time factor is shown in Figure 4.

Another particularly important indicator describing the efficiency of FMS projects is profitability.

Conventionally, it is defined as the ratio between the annual profit of already loaded facilities and full initial value of the project's production assets.

Accounting for the time factor, the profitability indicator is calculated as the average annual profitability of capital costs in the formula:

$$P = \frac{\frac{\sum_{t=\gamma}^{T} (P_{pr})_t}{n}}{\sum_{t=1}^{n} (K)_t} \cdot 100 \qquad (5)$$

where P is average annual profitability.

Proceeding from the data of Table 1, the average annual profitability of introducing FMS, calculated by formula 5, will be Levs 50.26, the average annual profit obtained per Levs 100 of capital costs.

The user's effect of adopting FMS is demonstrated most precisely by the indicator for average annual net profitability. This indicator is important also for determining the minimum requirements for acceptability. This is defined by the formula:

$$P_n = \frac{\frac{\sum_{t=y}^{T} (P_{prn})_t}{n}}{\sum_{t=1}^{n} (K_{pr})_t} \cdot 100 \qquad (6)$$

where $(P_{prn})_t$ is the present value of net profit in thousand Levs for every year with $t = 1, 2, \ldots, n$ (Table 1, line 7), P_n is the average annual net profitability.

The net profitability calculated by formula (6) using the initially assumed data is Levs 12.89 (average annual profitability per every Levs 100 of capital costs).

These results are too optimistic if compared with what the real indicators are, since our initial assumption was that FMS installation takes place under the best economic conditions. Practice has, however, proved that some of the parameters outlined at the stage of investigation and design would most often deviate and quite unfavorably at that.

The initially fixed total expenses and current production costs are often exceeded, sometimes heavily, so expected effects are not achieved, construction and full operation are unduly extended in time, etc.

All these realities necessitate a more feasible assessment of economic efficiency resulting from unexpected changes in construction and operation time limits, the amount of capital outlay, the income of realized products, their prime cost and the amount of foreign currency incomes and expenses.

It is justifiable to expect FMS construction and operation time limits to exceed the planned ones. That is due to possible changes in economic conditions, to delayed deadlines for equipment delivery and, also, to a number of psychological barriers like the need to adapt to new techniques or machinery, re-training, etc. The expected total costs may also be increased considerably when software deliveries are not guaranteed nationwide.

The incomes of realized products, especially in the initial years of operation are often lower than expected and production costs are larger. Foreign currency incomes may be lower than the initial expectations and currency expenditures may exceed those originally planned for.

Proceeding from these considerations we now estimate FMS pay-back time and profitability in such strained circumstances assuming that:

1. capital costs will amount to Levs 40 million due to rising prices of equipment (and not Levs 31.56 million as envisaged in the project)
2. the period of construction will be three years (and not two)
3. the period leading to full operation will be three years because of the short supply of investment capital, construction facilities, vendor's delays of machinery delivery, and other difficulties in reaching full capacity
4. profits turn out to be 20 percent lower than the planned ones due to strong competition, higher prices of supplied components and energy, greater depreciation deductions and wages rising faster than expected.

The starting data for the economic efficiency of the FM project are summed up in Table 2, and the capital costs and the profit, as influenced by the time factor, are shown in Figures 5, 6, and 7. The huge difference between indicators calculated on the basis of nominal value and those influenced by the factors of time and economic risk is seen in Figures 8, 9, and 10.

Table 2. Initial data for estimating the economic efficiency of FMS introduction with economic risk.

	1984	1985	1986	1987	1988	1989
Capital costs '000 Levs	4000	13000	15000	5000	1500	1500
Present value -/-	4000	11817	12390	3755	1025	932
	1987	1988	1989	1990	1992	1994
Balance profit -/-	8000	1000	15000	16000	20000	23000
Present value -/-	6008	6830	9315	9024	9340	8878
	1987	1988	1989	1990	1992	1994
Net profit -/-	2000	2500	3800	4000	5000	5700
Present value -/-	1502	1708	2360	2256	2335	2200

Under unfavorable production and economic circumstances the FMS pay-back time becomes 4.4 years (about 52 months) and not 23 months as according to the initial project. This means that in the case under study here, the accumulated present value of balance profit will manage to cover the present value of capital costs not earlier than the first half of 1991. The pay-back time calculated with and without the impact of time and economic risk (presen values) is described in Figure 11.

With these unfavorable conditions the profitability of the FMS project will be Levs 24.46 of average annual profit per every Levs 100 of capital expenditure (50.26 according to initially expected conditions). See Figure 12. Net profitability will be Levs 16.16, see Figure 13.

Thus, the comparison between the estimated pay-back time and profitability of capital costs under strained economic and production conditions, and the same amount envisaged by the project, shows that FM economic efficiency is highly sensitive to the factor of economic risk.

When required this technique helps us to calculate the quantitative effectiveness of FMS economic efficiency to strained (or favorable) fluctuations of construction time, time of coming into operation, estimated costs, balance profits, etc.

The assessment technique demonstrated in this paper offers a way of approaching feasibility studies which may prove essential before making decisions building or adopting FM systems, i.e., the comparison between the FM economic indicators and these of projects for conventional CNC technologies. The FM decision should be based on well argued higher levels of efficiency. This method also provides a way to bind decision-making into relevant economic conditions.

Conclusions

The theoretical reasons discussed above, and the calculations made on this basis, allow us to draw the following conclusions.

1. FM systems are a higher level of production but their adoption is merely another precondition and not a guarantee for higher production efficiency.
2. The estimation of efficiency of this new production organization should proceed from its special features, and particularly to its property of flexibility.
3. Efficient economic practice needs to know the techniques of estimating the specific effects of comprehensive production automation with respect to the influence of time and economic risk, upon its indicators for efficiency.

Fig. 1

ESTIMATE OF CAPITAL COSTS OF BASIC INVESTMENT FOR FMS INTRODUCTION

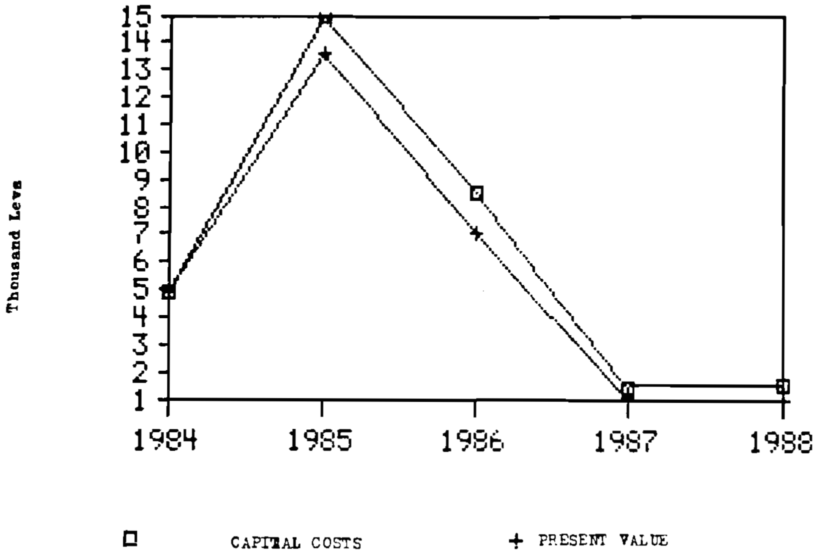


Fig. 3

ESTIMATE OF NET PROFIT FROM FMS INTRODUCTION

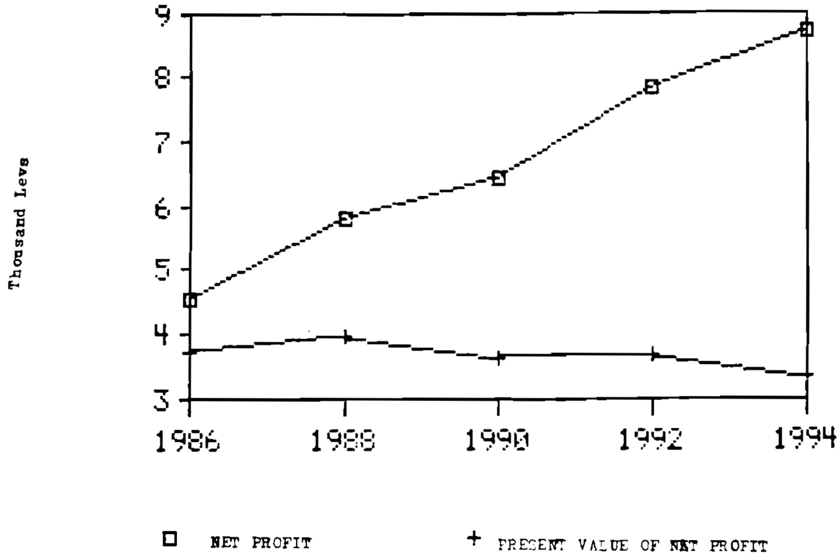
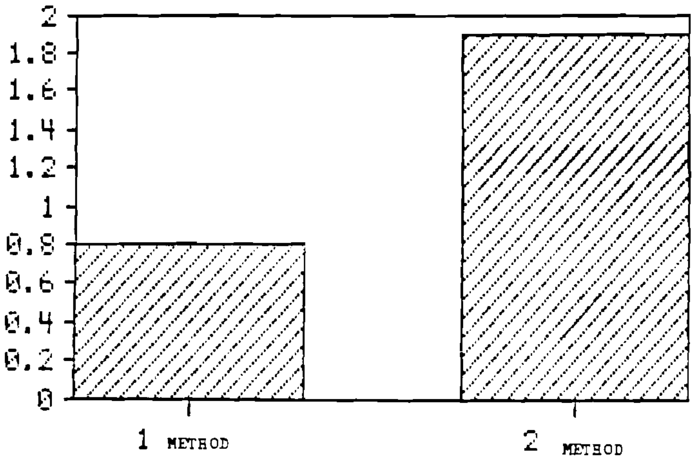


Fig. 4

ESTIMATE OF THE FMS PAY-BACK TIME (in years)



1st Method - Estimate of the FMS pay-back time without the impact of the time factor

2nd Method With the impact of the time factor

Fig. 5

ESTIMATE OF THE PRESENT VALUE OF THE CAPITAL COSTS OF THE FMS BASIC INVESTMENT

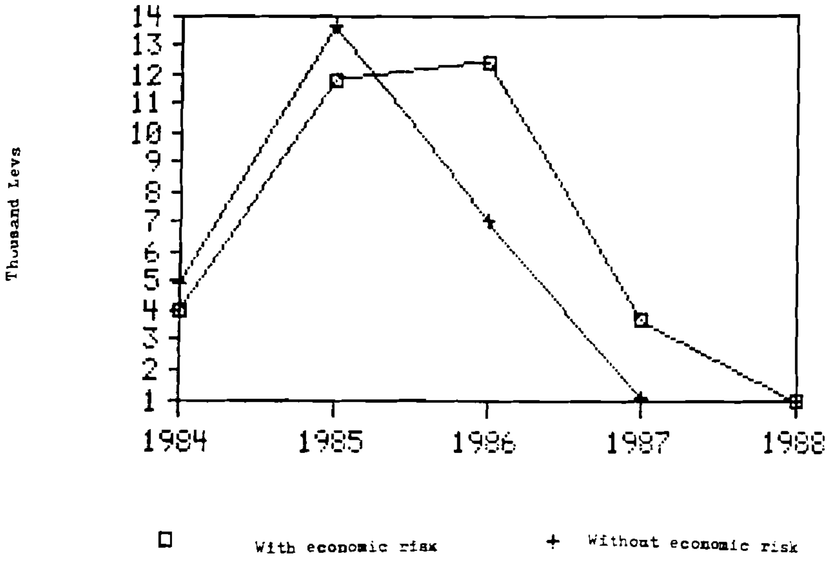


Fig. 6

ESTIMATE OF THE PRESENT VALUE OF FMS BALANCE P IT

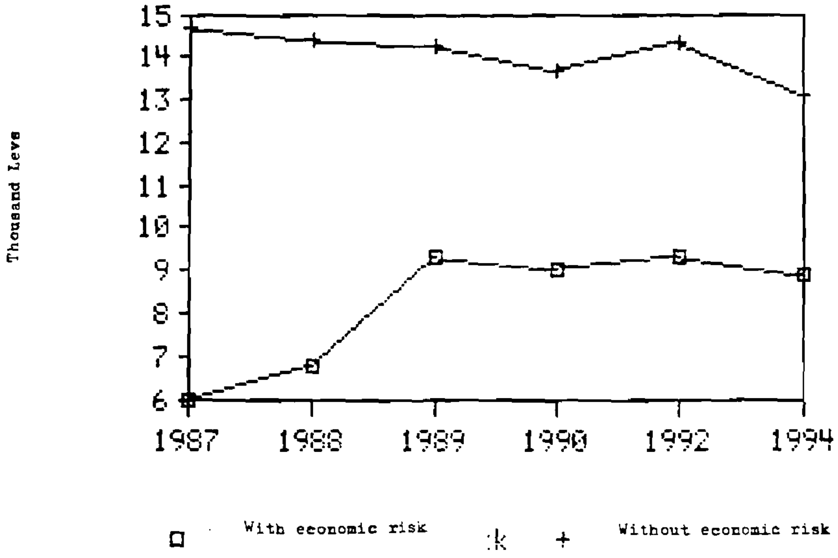


Fig. 7

ESTIMATE OF THE PRESENT VALUE OF FMS NET PROFIT

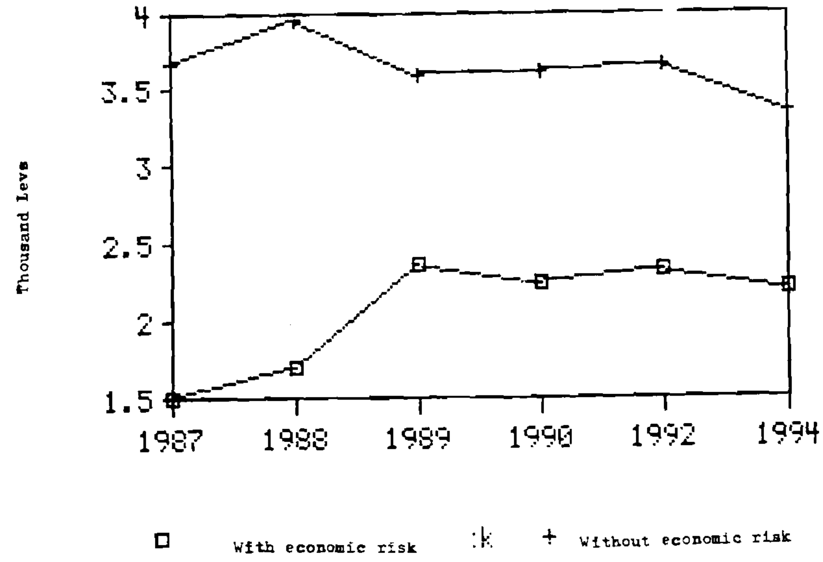


Fig. 8

ESTIMATE OF CAPITAL COSTS FOR BASIC INVESTMENT AND THEIR PRESENT VALUE IN CONDITIONS OF ECONOMIC RISK

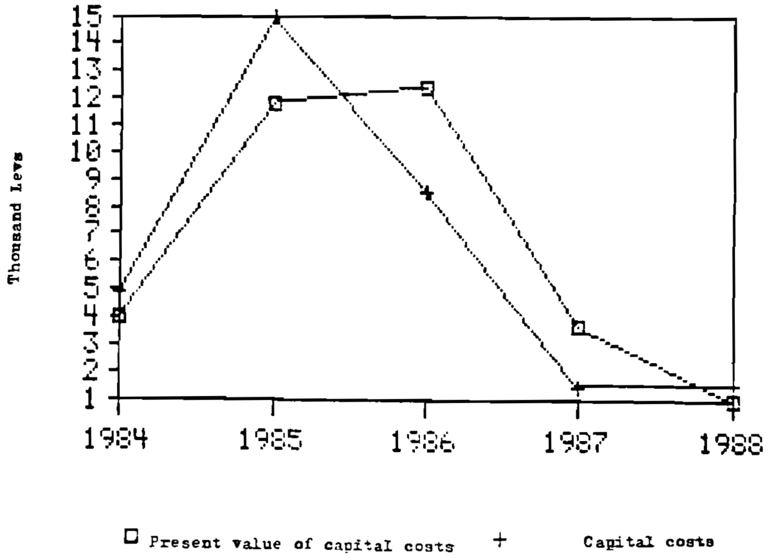


Fig. 9

ESTIMATE OF BALANCE PROFIT AND ITS PRESENT VALUE IN CONDITIONS OF ECONOMIC RISK

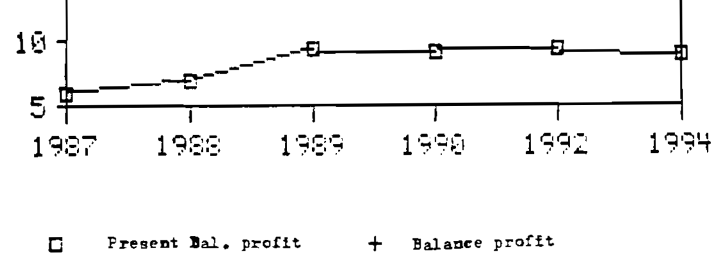


Fig. 10

ESTIMATE OF NET PROFIT AND ITS PRESENT VALUE IN CONDITIONS OF ECONOMIC RISK

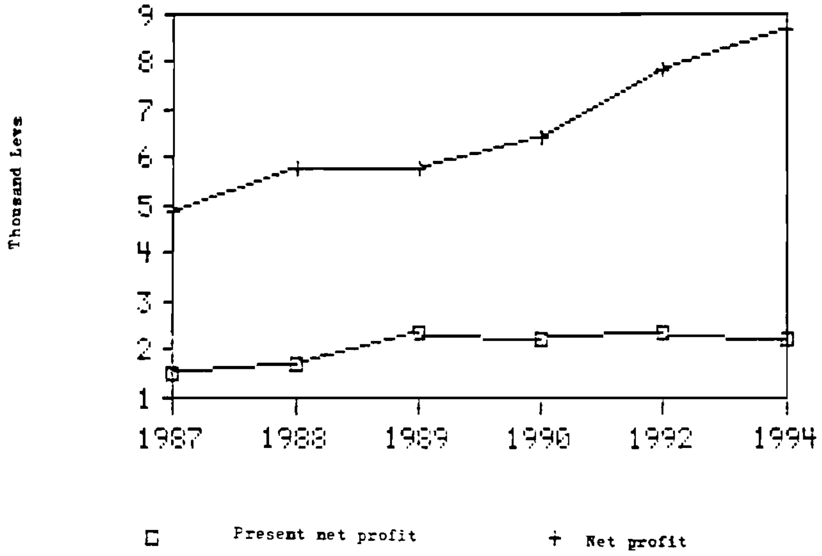
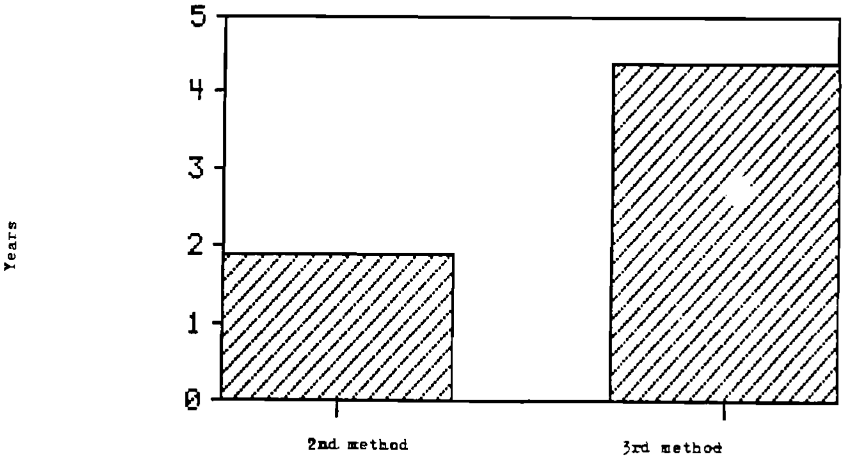


Fig. 11

ESTIMATE OF A FMS PAY-BACK TIME



2nd method– Estimate in present values of initial project indicators

3rd method – Estimate in present values in conditions of economic risk

Fig. 12

ESTIMATE OF THE AVERAGE ANUAL PROFITABILITY OF FMS INTRODUCTION

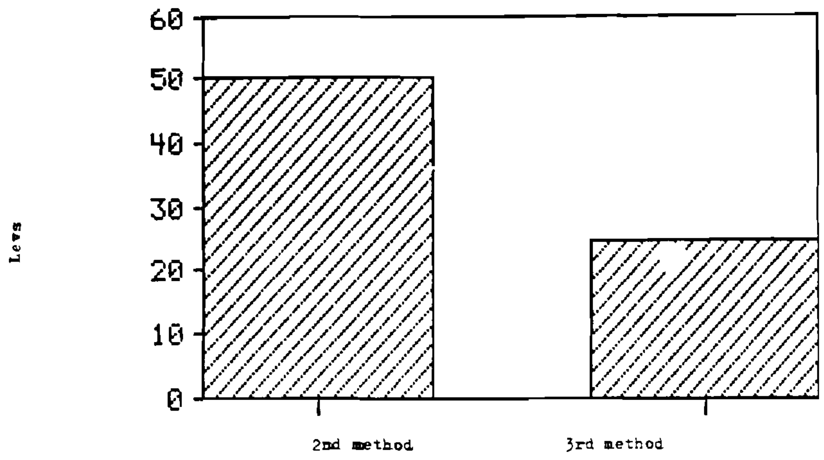
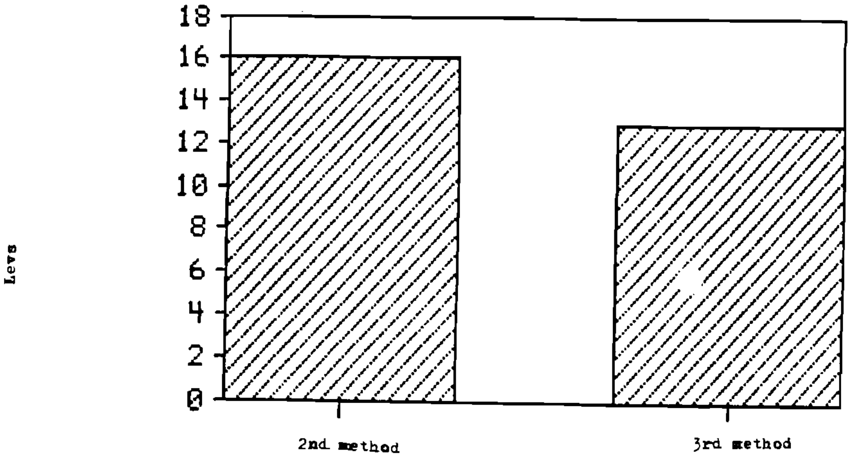


Fig. 13

ESTIMATE OF NET PROFITABILITY OF FMS INTRODUCTION



Analyzing the Impact of CIM by Econometric Models

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ANALYZING THE IMPACT OF CIM BY ECONOMETRIC MODELS

1. INTRODUCTION

The purpose of using econometric models for analyzing the economic impact of technological change such as the CIM diffusion can be briefly summarised as follows:

1. To put things together. If we have a conceptual model of the causal relations due to technological change an econometric model can allow us to describe the sometimes very complicated links in a single simultaneous model.

2. To test. If we have a hypothesis of the likely consequences of technological change the model can help us verify or reject this hypothesis.

3. To quantify. The econometric models also provide the possibility to describe an otherwise qualitative relation in quantitative terms.

4. To analyze. The models serve not only to test our "exogenous" hypotheses but their results can inspire the generation of new ideas and theoretical conclusions.

5. To forecast. Of course the econometric models are (at least for the time being) the most powerful tools when it comes to studying the future.

The limited resources which were available within the CIM Project were not sufficient to construct the sophisticated environment which would be required to approach the problem in full detail and scope. However, their results are quite interesting especially if we regard them in the general context of the CIM Project. In this brief survey we try to compare the methodological approaches to the problem, the assumptions made by the different authors and their main results. The studies on which we focus are those of Mitsuo Yamada (Yamada, 1990), later on referred to as Y-model, the Polish team lead by L. Tomaszewicz (Tomaszewicz et al., 1990; P-model), Rumen Dobrinsky (Dobrinsky, 1990; D-model) and Shunsuke Mori (Mori, 1990; M-model).

2. THE METHODOLOGICAL APPROACHES

The econometric studies of the impact of CIM technologies were based on different methodological approaches but they have one feature in common: they address these issues from a macro prospective, i.e., on a national and/or sectoral level. The only exception is the M-model which is a combination of macro and micro performance. Another common feature is that they focus on the diffusion of CIM technologies mainly in the metalworking industries which obviously are and will be the main recipients of this technological development. The Y-model and the P-model are based on input-output models in a Leontief-Keynesian framework (demand-driven, with an econometric block of final demand); the D-model relies on a supply-driven neoclassical growth model and the M-model is based on a specific type of production function.

The Y-model and the P-model are rather similar in structure and actually they were built on the same data base for the analyzed countries (Japan, USA and FRG in the case of Y-model and Japan and USA in the case of P-model). The input-output tables have been specially designed for this excercise by aggregating original input-output tables into 21-sector tables but with a disaggregated representation of the five metalworking sectors.

There are, however, some important differences in introducing the links between the CIM diffusion process and the economic performance.

The Y-model (fig.1) is more comprehensive in this sense as it considers the impact of CIM diffusion in terms of changes both in the input structure (the technological coefficients of the I-O matrix) and in the final demand structure (the consumption and investment coefficients). The changes in final demand drive the technologically changed I-O model to define the corresponding output. Besides, the Y-model relates directly technological change to labor productivity. Output and labor productivity are used to determine labor demand.

The P-model (fig. 2) does not consider CIM-induced changes in the A-technological matrix; besides, consumption is modeled by demand functions which are not directly linked to the CIM diffusion process. The impact of CIM is reflected in two ways: a) through the labor substitution effect and change in capital productivity; b) through the capital requrements for new equipment. The latter is transformed into changes of investment demand and through final demand this

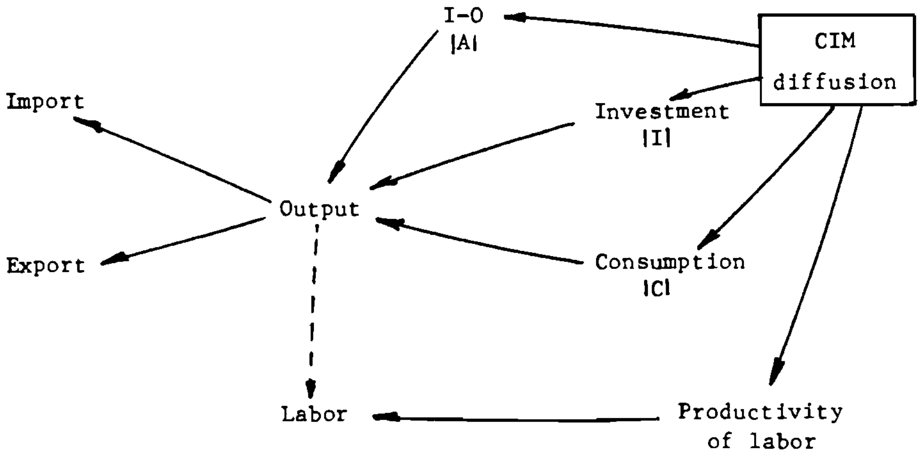

Fig. 1. Causal relations in Y-model.

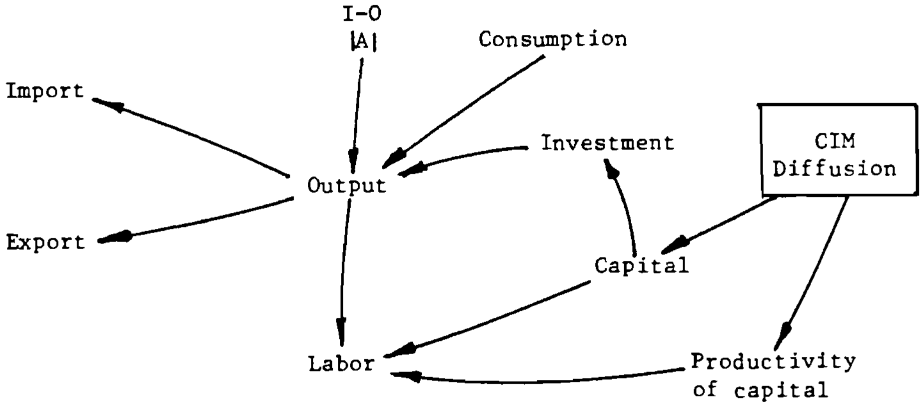

Fig. 2. Causal relations in P-model.

influences the level of output. On the other hand changed capital, changed labor and changed output through a production function determine labor demand.

The D-model (fig. 3) is essentially a supply-driven neoclassical growth model and due to this nature leaves less space for feedback maneouvers. The CIM diffusion is described in detail in terms of changes in labor productivity in the five metalworking industries. This in turn is translated into changes in the level of technical progress which causes changes in output. There is an additional loop output - investment - capital - output which transmits an additional spill-over effect. Potentially there exists the possibility to include links labor productivity - labor (basically the latter is exogenous) and technical progress - capital turnover but they were not used in the actual simulations.

The production function in the M-model (fig. 4) is designed in such a way that it allows to assess directly the labor enhancement effect of robot penetration. Under a cost minimizing behavior the firms select the optimal combination of workers and robots. Assuming an exogenous level of output the M-model allows to study the impact of two policies: robot penetration with endogenous labor (Policy 1) and robot penetration with exogenous labor (Policy 2).

We shall comment briefly on the "costs" and "benefits" of the methodological frameworks and the specific assumptions of the different authors.

The input-output framework is undoubtedly the most consistent and the one which theoretically allows to capture most comprehensively the potential impact of technological change on economic performance. There is, however, one crucial point in the implementation of I-O models for forecasting and that is the projection of the A-matrix and of other structural coefficients in the future. Technological matrices change over time and the reasons for this are technological changes in production as well as general changes in economic structures. Therefore in forecasts it is essential to define precisely the anticipated changes in the technological matrix and the assumptions leading to them. Of course this is by no means a trivial problem and it requires the input of substantial efforts. The classical approach is the well known RAS method but there are other methods as well. For example Leontief is more inclined to apply expert knowledge in forecasting the technological coefficients (see Leontief and Duchin, 1986); some more sophisticated versions of the RAS technique have also been developed recently (Snower, 1990).

In the two I-O based studies only Yamada tackles this problem assuming a time trend for the A-coefficients based on past observations. This approach does not allow to distinguish precisely which future changes in A are

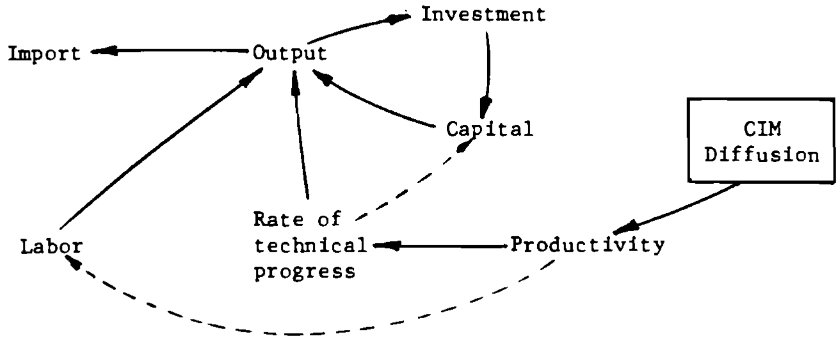

Fig. 3. Causal relations in D-model.

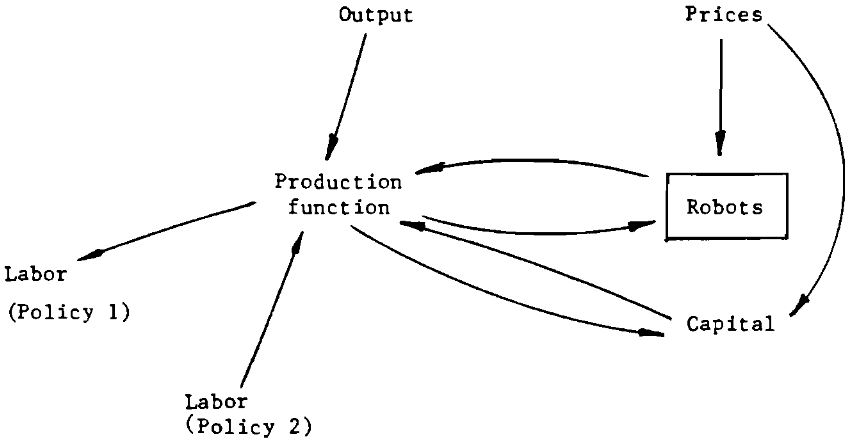

Fig. 4. Causal relations in M-model.

actually due to technological change (and, going further, which are caused by CIM) and which are due to other factors. The same is valid for the consumption and for the investment coefficients as well. Anyway, this is step afore as compared to leaving the structural coefficients unchanged.

The Polish team tried to incorporate explicitly the CIM diffusion scenarios in their model in terms of the capital structure and labor substitution effects in the metalworking industries. They ignored, however, the other important links to the input and final demand structures.

In general the input-output approach is a time-consuming and expensive one. Of course the invested effort always pays off but the limited resources of the project did not allow to extend this study beyond 2 - 3 countries.

The neoclassical growth framework applied in the D-study is rather limited in scope as compared to the I-O one. The supply-driven approach is less flexible with respect to analyzing the economic interrelations. On the other hand this approach allows to describe precisely the CIM diffusion scenarios and to assess the pure effect of this technological development. The models are quite simple and it was possible to cover in this study as many as 11 countries.

The M-model is more specific as compared to the other three as it addresses developments on a sectoral level. We could point out as its most advantageous feature the possibility to assess the direct labor substitution effect of the new technology.

Summarising our comments we are tempted to say that an ideal methodological framework to analyze the economic impacts of CIM would be an input-output model considering structural changes in input and final demand as the Y-model, the effect on capital and productivity as the P-model, describing the CIM diffusion scenarios as the D-model and the labor substitution effects as the M-model. In addition, however, it should allow to distinguish explicitly the structural change due to technological change and, in particular, to CIM diffusion.

3. THE ECONOMIC IMPACTS OF CIM: COMPARISON OF SIMULATION RESULTS

One of the major general findings of the IIASA CIM Project is the really revolutionary effect that CIM is expected to have on virtually all aspects of economic, social and even political life. This is highlighted by the results presented in all five volumes of the final report. As to the direct benefits of CIM Ayres and Bodda (1990) briefly summarise them as follows:

- labor saving;
- capacity augmenting/capital saving;
- capital sharing/saving;
- product quality improvement;
- acceleration of product performance improvement.

The combination of all these effects results in an overall reduction of payback time for CIM-type equipment and, in the final run, in a general acceleration of the capital turnover and increase in capital productivity.

It is not realistic to expect that any model could address in detail this rich variety of effects and their interrelations. Turning back to the econometric models we can see that they are rather modest in scope and treat only some specific macroeconomic issues in terms of CIM-induced changes in economic performance. As the models which were built by the different teams are different in nature so are the issues that the authors address in simulations. The results of these simulations are well described and analyzed by the authors so we shall only concentrate on the comparison of the different findings as well as on the some general conclusions concerning the expected socio-economic impact of CIM.

Table 1 presents an overview of one of the most important characteristics of three of the models - the Y-model, the P-model and the D-model, namely their sensitivity to CIM diffusion, according to the simulation results. The results shown in this table describe the response of the models in a scenario run with CIM diffusion as compared to a non-CIM scenario.

Table 1. Sensitivity of Models to CIM Diffusion

Country	Japan			USA			FRG	
Model	Y	P	D	Y	P	D	Y	D
GNP (real)	+	+	+	+	+	+	+	+
Exports	+	+		+	+		+	
GNP Deflator	-	-	-	-	-	+	-	-
Wage (nominal)	-	-		-	-		-	
Wage (real)	+	+		+	+		-	
Consumption	+	+		-	+		-	
Housing Investment	+	+		-	+		-	
Business Investment	+	-	$+^{1)}$	-	-	$+^{1)}$	+	$+^{1)}$
Imports	+	+	+	-	-	+	-	+
Employment	+	+		+	-		-	
Rate of Unemployment	+	-		-	+		+	

"+" - positive response; "-" - negative response; " " - the variable is not analyzed in the model.

1) Total Investment in the case of the D-model.

Although there is not a full synchronism in the reactions of the models there are some remarkable similarities which are symptomatic about the expected impact of CIM.

The first important symptomatic result is that in all experiments GNP responds positively to the CIM diffusion, i.e. CIM leads to a higher economic growth in the countries. The evaluated quantitative effect on GDP in the different studies is of comparable magnitude and scale and the cross-country differences can be attributed to the different weight of the metalworking industries in the economies (higher in Japan and FRG and lower in USA).

Another identical response is the negative response of the GNP deflator to the CIM diffusion (USA in the D-model is the only exception due to a specific function for the velocity of money). The most important factor for this (together with other factors which we shall consider later) is the reduction of unit costs caused by the CIM equipment.

A third symptomatique is the positive change of exports. Among other factors an obvious reason for this is the increased competitiveness of exports due to the already mentioned decrease in domestic prices.

A fourth similar reaction in the positive change of the real wage (with the exception of FRG in the Y-model). Although the nominal wage rate in general responds negatively the absolute level of its change is smaller than that of the price deflator which results in a positive change of the real wage. This in turn leads to an increase in effective demand which in a demand-driven model further increases output and GNP.

Actually in the CIM results of the two demand-driven input-output models one can trace an almost pure Salter cycle: the more productive CIM technologies introduced in the metalworking sectors cause reduction in labor demand; this reduces labor costs and leads to price decreases; the latter stimulates demand and induces an increase in output. In his study Yamada (1990) analyzes the Salter causality chain in quantitative terms.

At the same time there are cross-country as well as cross-model differences in the response to the CIM shock. Thus the rate of unemployment in Japan responds positively in the Y-model and negatively in the P-model. The rate of unemployment in the USA manifests exactly the opposite reaction in the two models - negative in the Y-model and positive in the P-model. There are differences in the responses of consumption, investment and imports as well.

There are three main reasons for these differences. The first one is connected with the differences in the modeling methodology (see the causality chains in figures 1 to 4). The second factor is the difference in some behavior equations in the model. As a third factor we could mention the country specific characteristics. The combination of these factors affects to a largest degree the labor demand (and subsequently, the level of unemployment) which is subject to various interrelated influences. In the Y-model the CIM diffusion is translated into changes of labor productivity and this in turn is used (through a labor demand function) to derive employment. In the P-model the technological change is expressed in changes of capital productivity which is thence fed to the inverse of a production function to determinethe labor demand. Due to the different responses which we get in the two cases the overall reaction of the economy as a whole can also be different what we observe in the results of the two models.

This well might be reason for the different estimations in the three studies of the effect of CIM diffusion on labor employment in the metalworking sectors (table 2). The results of the Y- and P-models are the directly evaluated figures for the decrease in labor demand in the five sectors in the CIM scenario as compared to a reference scenario. The D-model which is supply driven does not allow for a direct estimation of the changes in labor demand so the figures presented there are only an indirect estimation. This estimation is made under the assumption that every newly created working place associated with CIM technologies (these figures are calculated in the model) causes an equivalent by labor productivity decrease in labor demand in the corresponding sector. The table contains also the estimated effects on labor due to robot penetration in Japan according to the results of the M-model.

The results for the effect on employment present a broad variety of responses to the CIM diffusion. Except for the reasons already mentioned this might also be caused by differences in the sectoral employment figures actually used by the different studies. Just as a very rough comment, the estimations of the Y-model in general seem a bit overestimated as the evavuated changes in labor demand approach levels comparable to the actual employment levels in these sectors at the present time. However, as stated above, this also might be due to a difference in the statistical base.

In any case these results as a whole reveal the dramatic structural change brought about by CIM which is going on at the present time and which will deepen substantially in the future. The sectoral impact concerning the level of output are also impressive - it may be expected that the CIM might lead to 50 to 100 per cent increases in the sectoral output of the metalworking industries by the year 2000.

Table 2. CIM Effect on Employment in Metalworking Industries

Sector (ISIC) Decrease in Labor Demand in 2000: CIM vs Reference Scenario (thousands)		381 Final Metal Products	382 Non-Electrical Machinery	383 Electrical Machinery	384 Transport Equipment	385 Scientific Equipment	38 Metal-Working Industries Total
Japan	Y-model	269	1384	1078	1058	213	4002
	P-model	551	461	731	466	126	2335
	D-model	265 ÷ 477	406 ÷ 725	568 ÷ 1000	319 ÷ 578	82 ÷ 153	1639 ÷ 2933
	M-model[1]			9% ÷ 15%	-8% ÷ 12%		
USA	Y-model	656	1035	818	1280	325	4114
	P-model	140	210	350	580	200	1480
	D-model	179 ÷ 341	543 ÷ 1015	721 ÷ 1363	653 ÷ 1207	272 ÷ 503	2367 ÷ 4429
FRG	Y-model	44	294	573	522	88	1521
	D-model	56 ÷ 110	257 ÷ 475	152 ÷ 292	187 ÷ 359	25 ÷ 47	676 ÷ 1283

1) 2000 vs. 1985; decrease only due to industrial robot penetration.

Note: The D-model estimates are made under the assumption that new CIM working places cause an equivalent (by labor productivity) decrease in labor demand in the corresponding sector.

4. CONCLUSIONS

In summarising the general conclusions from the econometric studies first of all we have to stress again that the models are capable of catching only certain aspects of the socio-economic aspects of technological change. One should be aware of this and should not expect from the models more than they can give. One obvious lesson is that traditional econometric models, such as the ones which were used within the CIM Project, are not relevant to capture the complexity of the phenomenon we try to study. However, it seems that no better models exist at the present time and this will clearly be a challenge for the future research.

However, within the scope of what the models can do there are some very interesting and encouraging results. The most important of these results in our view is the presence in the different studies of a stable set of identical, or at least similar, indicators describing the economic performance of the countries under CIM diffusion (the "symptomatic" results which we discussed in the previous section). The fact that these results were arrived at in independent studies increases considerably the reliability of the findings. We could point out here the expected influence of CIM on economic growth, exports, prices, real income as well as the overall effect in the form of the Salter cycle.

There is at the same time a set of areas where the expected impact of CIM is not so clearly defined. We could mention here the overall effect on employment, the impact on consumption, investment and imports. These aspects may well be considered as country specific but on the other hand they clearly deserve a deeper insight in the future studies.

It is a pity that some interesting issues such as the cross-sector CIM sensitivity of the models were not analyzed separately in any of the econometric studies (this is well within the analytical power of the models). Such analysis might be helpful for the evaluation of the pure spill-over effect of the CIM diffusion. This is also one possible line for future research.

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The Use of Aggregated Econometric Input-Output Models For Macroeconomic Impact Analysis of CIM Technologies*

by

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Introduction

This paper is devoted to issues of the macroeconomic impacts of Computer Integrated Manufacturing technologies. The analysis of new technologies in the context of economic growth and structural change of national economies is an important aspect of systems analysis of innovation processes. Beyond direct economic impacts new technologies cause a variety of induced effects due to the interrelations between the economic system and the production activities immediately affected by these technologies.

Analyzing macroeconomic impacts of CIM technologies, we can rely on a considerable stock of scientific and practical results and on a variety of proven tools both for research and decision support purposes.

In the field of practical experience at least the following three "roots" of further research are worth mentioning:

1. previous studies on macroeconomic impacts of CIM and related technologies, using input-output techniques and econometric models, for example, Fleissner et al. (1981), Leontief/Duchin (1986), Howell (1985), Ayres/Brautzsch/Mori (1987) and Kinoshita/Yamada (1988). Ayres et al. (1987) compared some of these studies, pointed out general methodological problems and drew some conclusions.

2. the experience of the IIASA CIM project on the analysis and forecasts of CIM technology diffusion and CIM implementation issues at the firm level. Within the CIM project there have been used logistic diffusion models, production function apparatus, and a technology penetration model at the linked macro and micro level (Tani, 1988).

   Calculations were performed for industrial robots and NC- machines on Japanese, US and CSSR data. A worldwide data base on flexible manufacturing systems (FMS) has been collected and analyzed from the viewpoint of cost/benefit performance, social and managerial issues.

   All these studies, together with related research results in other institutions in different countries, will provide a more or less comprehensive description of the diffusion process of CIM technologies.

3. "Multinational" experience in using economic models for macroeconomic analysis. This paper focuses on econometric input-output models tracing the causal chains of macroeconomic impacts both in terms of interindustry relationships and of interdependences between economic variables describing economic behavior, and basic balance equations. Compared to "pure" input-output, the econometric extension of these models helps to overcome some of their disadvantages, connected with the relative rigidity and one-sidedness of the concept.

   The development of the IIASA-INFORUM family of econometric input-output models and the dissemination of the G and SLIMFORP special software packages by IIASA were important contributions to this field of research. (see Input-Output and Porter [1984]).

   For the purpose considered here, the model structure is specified according to some concept of possible paths of the macroeconomic impact of CIM. That does not mean, that the model is to be built "from new".

However, pure extrapolation of previous practical experience might with time lead to a certain "research bias", if not regularly confronted with the underlying theoretical concepts. The main pillars of the theoretical background of our research subject should be considered innovation theory, systems analysis, and structural dynamics.

In brief:

1. Innovation theory substantially improved our knowledge about inner laws of technological development. Two aspects of the characteristic way of thinking of this theory are especially important for macroeconomic analysis: the time performance of technological development and the concept of technological interdependences between industries.

   The first aspect includes the concepts of product and technology life cycle and dynamic efficiency as well as long-term aggregate time behavior of innovations, of basic technological indicators and of the economy as a whole, appearing in the form of "long waves", medium-term and short-term cycles.

   The second is connected with linkages between innovation processes in different industries, the driving forces, economic mechanisms and diffusion paths of new technologies. Thus initial and induced innovations, motive, career, and induced branches are considered e.g. Perez [1984], pp.62-63. A similar concept was applied by Ranta [1988] to the case of CIM technologies (see pp. 5- 7).

   A certain synthesis of these two aspects is expressed by the terms of "technological paradigm" (Dosi, [1984], p. 14-15) and "technological style" (Perez, op.cit., p. 59). Thus innovation theory provides the theoretical background for the diffusion analysis of any particular new technology. It also allows us to locate both in space and time a particular innovation process within the framework of interrelated innovations of the present technological transformation.

2. Systems analysis whose characteristic interdisciplinary, complex, dynamic and "unprejudiced" systems approach is likely to avoid biased conclusions, caused by the restriction of the research to a particular subject - macroeconomic impacts of CIM, and to a particular class of tools - econometric input-output models.

   In the case of CIM technologies social impacts in a broader sense are worth mentioning. New technologies in the long-run deeply affect style and quality of life, institutional and organizational patterns of society. Modern forms of manufacturing automation change contents of work. New qualification structures and even education strategies are desired (Leontief, 1986) (Fleissner, et al, 1981). Finally, new technologies must improve the relationship between man and nature (Leontief, 1970, 1972, 1973).

3. Structural dynamics denotes a particular concept in economic analysis, which is concerned with the influence of technological change on the industry structure of the economy and, in particular, of employment. The studies on these issues can be traced back to the analysis of the impact of machinery on the level and structure of employment, e.g. Marx (1974). A later contribution to this field of research is the work of Pasinetti (Pasinetti, 1981).

   Structural dynamics can justly be considered the connecting link between innovation theory and structural analysis with the help of economic models divided by industries. These models are used in economic theory e.g. Pasinetti. This link helps to bridge a gap between innovation theory and structural analysis as two rather different ways of looking at economic systems.

   So far as these models are also tools for practical calculations and for decision support, this link connects different levels of abstraction. It provides the theoretical background for measuring technological change in terms of economic models reflecting industry structure. Dosi also refers to these two important fields of research (Pasinetti, 1981).

There is an obvious need for systems analysis and impact studies of new technologies on the national level in all industrialized countries. Nowadays we are facing a possible increasing role of government science and technology policy both in market and centrally planned economies.

Beyond the practical and theoretical background of the analysis, this is another essential starting point for economic modeling of macroeconomic impacts of CIM. For the design of a model it is important, whether the model is to be used in economic theory or for policy formation.

In this connection, it is useful to distinguish the following "application modes" of economic models:

1. Application in economic theory is focused on qualitative relationships. Calculations are often performed on analytic expressions rather than actual data.
2. Application in "applied branches" of economics up to dedicated applications for decision support in some "advisory mode", e.g., in the field of government policy formation.
3. Implementation of economic models within the framework of interactive decision support systems. While in an "advisory mode" model-users fully depend on model- designers, in this case, for instance, policy makers or officials in government institutions could analyze different scenarios of government policy in a certain field without permanent assistance of model-designers.

In the last two cases special requirements must be met by the models:

A. The set of endogenous and exogenous variables and the degrees of freedom of the model must reflect the actual decision making problem or decision situation. Fixed preconditions and the scope of the decision in terms of the actual control variables must be taken into account (Johansen, 1978).

B. So far as there is a certain division of labor between model-designers and model-users, to the latter should be transmitted not only "pure" results, but also the knowledge of underlying assumptions and limitations of the model.

From this some conclusions for macroeconomic impact analysis of CIM technology diffusion should be drawn.

First, while aiming to support policy formation in this field, the potential user of the model as well as the actual decision problems have to be specified.

Secondly, any finding of macroeconomic impact analysis must be considered in the context of possible responses of government policy.

Expected trends in employment, level and structure of qualification, and contents of labor should be met by appropriate strategies and structures of education, re-education and supporting social policy measures. Conclusions for investment allocation or, say, assignment of subsidies, should be derived from the well-known multiplier effects.

Thirdly, one should not expect unconditional acceptance of the results by the decision makers. Responsibility for decisions is incompatible with inscrutability of means of decision. That's why user-friendly verification tools as mentioned above are needed even in the case of conventional, seemingly simple methods like input- output analysis.

The following analysis will start with the concept of networks of causal chains. Afterwards possibilities of analyzing causal paths of macroeconomic impacts of CIM technologies will be demonstrated. Then an aggregated econometric input-output model of the US economy and the product chain analysis software will be described in brief as examples of tools for the analysis of these issues.

Economic Models and Networks of Causal Chains

An economic model is the reflection or description of the causal relationships between the inputs, the state and the outputs of an economic system.

The main purpose of the often real "Sizyphus" work of model design and data collection is to provide means for the analysis of possible impacts of input (or control variable) changes on system behavior - first of all on its outputs. Thus the idea is to obtain optimal control strategies to gain desirable or sustainable system outputs.

This rather simplified outline of economic modeling, nevertheless, provokes some serious questions: How to describe both quantitatively and qualitatively determined causal relationships? How to ensure all important causal interconnections with considerable influence on systems behavior are included? How to define "desirable" or "sustainable" outputs? Can we really trust a model, which in any case provides an abstract, simplified idea of real life? How to reflect within the model not only the control strategy but the "control philosophy" as well, i.e. the choice of the set of control variables rather than their actual values?

We may pose the question, "what kind of economic models could be used for the analysis of macroeconomic impacts of CIM technologies?"

First one could consider a more descriptive, "black box" approach, analyzing, e.g., the correlation between aggregated dynamics of a national economy and some indicators of CIM technology diffusion and their dynamic efficiency. Yet, there is one great disadvantage. These models only to a very limited extent allow tracing causal chains from technology diffusion to macroeconomic impacts. They indicate some aggregate linkage, which at least in part may be fictitious, even if statistically significant.

Thus a kind of model is desired, which reflects the production processes affected by new technologies as a well-defined subsystem of the national economy and at the same time allows tracing causal chains to macroeconomic behavior (including feedbacks).

This model will not be a "black box" but specify the network of relevant causal chains in an explicit form. Giving the possibility to attribute changes in aggregate behavior to "elementary" causal chains, the model simultaneously will provide the base for the verification tools mentioned above.

A thorough systems analysis of the CIM technologies is desired not only for scenario design but also for model selection.

Here some words about the concept of causality are needed. This concept seems to be too restricted in many cases because of its unidirectionality. Yet in real life most of relations between things, phenomena, processes or concepts are interdependence, interrelations with cause and effect changing their places and not absolutely attributable to one of the sides of the relationship.

So in economic models a so-called "independent" variable often can well be replaced by another one, simply transforming the expression and bringing out the new variable to the left side instead of the old one.

But causality in its philosophical sense does not include unidirectionality, and mathematical models allow for interdependences by introducing feedback loops between variables as well. The reflection of steady states, equilibrium or disequilibrium in economic models is based on these feedbacks and loops.

Another issue connected with causality in economic models is that of spurious correlation. Often it is caused by similarities in time trends of economic variables, which are not really interrelated directly.

Dealing with networks of causal chains in economic models it is necessary to distinguish at least three levels of analysis:

1. the network of flows, i.e. interindustry flows of materials, flows of capital and consumer goods;

2. the network of measurable causal relationships between economic variables;

3. the conceptual network of qualitative causal relationships, e.g., between initial and induced innovations in different industries (in other terms - the network of diffusion paths) or the causal chains of social impacts in a broader sense, including, e.g., consequences for education concepts and leisure time behavior.

economy requires a certain level of aggregation. Selected technologies like CIM, robots, NC machines and CAD/CAM can be measured and analyzed only on a relatively detailed level.

If one decides for the connection of a detailed representation of the new technologies with an aggregated model of the economy, the main task to be solved will be the linkage between these two parts of the model.

It is rather difficult, for instance, to identify the material flows caused by a specific technology within an aggregated industry classification. Due to the aggregation level, a part of them will even appear as inner flows of some industry.

Another part will not appear at all in an I-O table because components might not be sold to other companies but will be consumed by the same company that produce them. Thus division of labor within and between companies will affect interindustry shipments as shown in the input-output tables.

Figure 1 gives some idea about the structure of the complex of CIM technologies. In the right part of the picture the technologies belonging to this complex and the linkages between them are represented.

Industrial robots and numerically controlled machines are used both in stand-alone applications and in flexible manufacturing or computer integrated manufacturing systems. Sheinin/Tchijov [1987, pp. 14/15] analyzed the number of robots and NC-machines included in FMS using the world-wide FMS database of the IIASA CIM project. Lakso [1988] studied the influence of FMS technology on the efficiency of NC-machines included in these systems. So in principle it is possible to describe these linkages also in a quantitative form.

Computer Aided Manufacturing (CAM) usually is an integrated part of all FMS and CIM applications. Yet until now the immediate linkage between Computer Aided Design (CAD) and CAM - the often stressed CAD/CAM is not a typical case.

On the left hand side of the figure some important innovative components of these technologies are shown. For the analysis of CIM technologies, with the help of input-output models, these components must be attributed to the appropriate sectors of the sector classification of the I-O model and to certain interindustry material flows represented in the I-O table.

New materials are required, above all, both for the semiconductor industry and for more reliable and precise tools as needed for computer-controlled machine tools with integration of different functions and automatic tool and workpiece changing. Modern control equipment, in-process gauging systems, servo-motors and laser systems (for gauging and orientation, e.g., of automatic guided vehicles - AGV) are also important new components desired for these technologies.

There is a class of components needed especially for FMS and more sophisticated CIM systems, which probably will change the input structure of FMS producers substantially - automatic guided vehicles, automatic pallet and tool changers and automatic storage and retrieval systems.

Finally, modern communication technologies play a key role in the integration process of CIM systems. Office automation is included in this process, so that there will be an efficient linkage, e.g., between production planning and process control. This will lead to higher software requirements. So far as software is bought from other companies, this will affect interindustry flows of services.

FMS and CIM will utilize their potential efficiency only if all manufacturing organization is modernized basically. New logistic technologies such as Kanban or just-in-time are mentioned here, because they will make the manufacturing flexibility of FMS and CIM a flexibility for the customers of the firm.

Figure 2 shows the main backward linkages of the commodity group "metalworking machinery and equipment" of the 85 sector U.S. input- output table for 1981, which in particular includes machine tools, among them NC-machines (U.S. Input-Output, 1987). For Fig. 2 and 3 a personal computer program called "Product Chain Analysis" was used. It has been developed at the Economic Research Institute of the State Planning Commission in Berlin/GDR. (The theoretical background and the facilities of the program are described in the appendix to the original working paper - WP90-19 available from IIASA).

The relationships in Fig. 2 look much more prosaic than the variety of key components of CIM technologies as shown in Fig. 1. The box on the right represents domestic output for final consumption of the commodity No. 47 in millions of 1981 dollars. Starting from this commodity, the product chain "Metalworking Machinery and Equipment —> Electrical Equipment —> Electronic Components —> Nonferrous Metals' is listed.

Every column of the figure represents a certain stage of the production process in terms of the 85-sectoral commodity classification of the U.S. I-O table. The products belonging to the chain are listed in double-line boxes. For every stage together with the chain commodity main components also consumed in the same process are shown.

It is necessary to attribute different components of CIM to the sectors of this model and to the flows between them. So electronic industrial control equipment has to be searched for in the "Electrical Equipment" commodity group, semiconductor components - in the "Electronic Components" group.

Software bought by the CIM technology users from other companies and not included in the system costs, e.g., of a FMS, appears in the sector "Business Services".

Figure 3 demonstrates another feature of Product Chain Analysis. It is possible to search within the direct material requirement coefficient matrix for all relevant product chains linking two commodities. If a sufficiently small tolerance value was used for the search, the sum of all these chains will accord with the Metalworking Machinery and Equipment, based on U.S. Input-Output Data for 1981 corresponding total requirement coefficient.

Industry No. 47 change over the period 1972-81. In table 1 the most important inputs (commodities) of this industry for the 1972, 1977 and 1981 I-O tables are compared. This comparison is based on the original "Use"- tables (i.e. commodities, used by industries) as published in the Survey of Current Business to avoid distortions due to the transformation algorithm.

Table 1 - Changes in Input Composition for Industry No. 47 "Metalworking Machinery and Equipment"

Mln.curr.$	1972		1977		1981
Total Output	7155		13157		22240
Value Added	4301		7820		12953
Intermediate Input	2854		5337		9287
Value Added/Output	60.1%		59.4%		58.2%
Interm.Inp./Output	39.9%		40.6%		41.8%
Input position	Flow	UMS	Flow	UMS	Flow
31. Petrol refining	50	-13	79	86	220
36. Stone/clay	58	20	127	0	215
37. Primary iron/steel	653	-20	1181	-45	1951
38. Prim. nonferrous	169	-10	301	-86	423
47. Metalworking M/E	409	-46	706	15	1208
49. General Ind. M/E	158	-19	272	23	483
50. Miscell. Machinery	172	-13	303	89	601
53. Electr.Ind.Equipm.	178	29	356	-25	577
65. Transp./Warehouse	58	28	135	2	230
69. Wholesale/Trade	181	82	415	105	806
73. Business services	152	-7	273	18	479
Sum of selected posit.:		33		181	
Sum of Intermed. Input:		89		266	

In the upper part of the table total output and the global cost structure of industry No. 47 are listed. One can observe an increasing share of intermediate input in total output. The data for different kinds of materials give a certain idea about possible causes for these cost dynamics. Together with the flows "unit material consumption saving" was calculated by the following formula:

$$\mathrm{UMS} = \mathrm{Flow(year2)} - \mathrm{Flow(year1)} * \frac{\mathrm{Tot.Outp.Ind.47(year2)}}{\mathrm{Tot.Outp.Ind.47(year1)}}$$

For most of this data there is no obvious explanation. Consider, for instance, the rapid oil price increase in the middle of the 1970's and the relative saving of petrol refining products between 1972 and 1977 (in current prices!).

The increase of material costs of industry No. 47 during this period is caused by the increasing consumption of electrical industrial equipment (this would correspond with the increasing role of industrial automation) and the growing consumption of two service groups: Wholesale/Trade and Transport/Warehouse.

The decreasing use (again in relative terms) of electrical industrial equipment in the second period could be explained by reductions in prices, and a higher share of electronic control equipment.

The reduction in ferrous and nonferrous metal consumption in both periods seems to be plausible. But why did the shipments of the metalworking industry to industry No. 47 in relative terms decrease in the first and increase in the second period? Is this caused, e.g., by changes in the organizational (property) structure of the metalworking industry or even by changes in preparation methods of the I-O table?

Answering all these questions requires time-consuming analytic work, but is indispensable for any impact study based on the input- output framework. It will be useful to utilize more detailed levels of input-output tables for these purposes. For the U.S. economy, e.g., beyond the 85-sector tables, desegregated data are available.[1] Unfortunately, the sector classification of these tables has been changed from one benchmark year to another, while the aggregated tables are, in principle, comparable.

Although the 85-sectoral classification seems to be too aggregated for macroeconomic impact analysis of CIM technology diffusion, it was used by different authors for this purpose (Leontief/Duchin [1986], Howell [1985]).

This short introduction to the subject "Input-Output and CIM' already provides the basis of the issues connected with this concept. The next section analyses the general methodological problems of using the input-output approach for macroeconomic impact analysis of the diffusion of new technologies.

Networks of Macroeconomic Impacts of CIM Technologies

The measurement of macroeconomic impacts of CIM technology diffusion is based on the underlying concepts of possible impacts. This concept can be described by some "conceptual network of causal chains" as developed earlier.

In Bonetto's work [1985] on flexible manufacturing systems one can find such a network written down as a graph (see Fig. 4).

This scheme includes a cost-price-demand feedback which is not reflected in models by Fleissner and Leontief/Duchin. In the model of Kinoshita/Yamada [1988] these feedbacks together with other additional impact chains are represented by behavioral equations. The underlying network of causal chains has been described by these authors in verbal form, and in Fig. 5 these relationships are demonstrated as a graph.

The authors distinguish supply side and demand side effects of industrial robot diffusion. The main driving force for robot application in the countries included in the model is, they

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[1] The classification for the detailed tables includes 365/496 commodities and industries for 1972 and 366/537 for 1977. 1981 is not a benchmark year - since 1980 BEA started to publish also intermediate years on the 85-sector level.

consider, labor saving, thus improve profitability and/or decreasing output price in the robot using industries.

With the help of the input-output part of the model it becomes possible to analyze induced price reductions in related sectors of the economy due to the lower output prices of robot using industries. On the demand-side, besides direct requirements caused by increasing robot shipments, input-output allows us to determine induced demand for components and materials, indirectly involved in robot production.

The econometric behavior equations included in the model afford the possibility of tracing further influences on foreign trade relations, as well as upon income distribution, private consumption a.s.o. On the other hand, the "effects in the foreign countries will be fed back with a certain time lag to the domestic economy through the channels of trade flow."

Thereby this model gives a real complex picture of the variety of direct and indirect impacts of a new technology.

Due to the combination of an input-output framework with econometric equations and an international trade flow model, the effects induced by interindustry relationships can be analyzed together with those caused by complex economic interdependences and international trade linkages.

The complexity of this model has been achieved at the cost of a relatively high aggregation level - 21 sectors. Even within the 85-sector classification of the U.S. input-output tables, it is very difficult to identify the main CIM components, it may therefore be almost impossible to determine, for example, increasing demand for robot components induced by growing robot application within a 21-sector framework.

A 13-sector Econometric Input-Output Model of the U.S. Economy

In this chapter a 13-sector econometric input-output model of the U.S. economy will be provided in order to discuss issues of practical calculations on the macroeconomic impact analysis of CIM technologies.

The main practical problem to be solved while designing a model for this purpose is to clarify, how technological change should be included in the model. Some possible approaches are briefly presented:

1. The Studies by Fleissner (1981), Leontief/Duchin (1986), Howell (1986), Ayres/Brautsch/Mori (1987), and Kinoshita/Yamada (1988) were based on models of national economies not especially dedicated to technology assessment and, in particular, not explicitly reflecting the mechanism and driving forces of technology diffusion themselves.

   Diffusion and the influence of technology were estimated separately in terms of possible changes of parameters and coefficients of the model. Therefore this approach could be called "exogenous parameter adjustment". In some cases, rather rough estimates were used (Kinoshita/Yamada, 1988, p.11). Leontief/Duchin utilized ample data from publications to predict parameter changes, but this information also was only in part based on statistical analysis and often was not reliable.

   Exogenous parameter adjustment could be improved using CIM technology diffusion studies performed at IIASA during recent years.

2. Carter [1987] described an approach to the analysis of technological change within an input-output framework, which is based on a simple decision rule for investment in new technologies depending on the gains from investing in additional capacity or replacing old capacity with new.

   This decision rule is the first step to the integration of a technology diffusion model into an input-output framework.

Therefore, future price changes of inputs and outputs by sector must be predicted. Thus, the "learning curve" concept can be reflected immediately in the model. On the other hand, any parameter prediction brings uncertainty into analysis, and even a simple investment decision rule will make it difficult to trace the consequences of uncertainty.

New technologies in a certain sector are represented by a new column of input coefficients for this sector, the capital cost per unit, and the expected price changes mentioned above.

3. For technology impact analysis, it might not be necessary to model the whole national economy, but only some subsystem of those production processes and their economic relationships, which to a certain extent are influenced by the new technology.

   Product Chain Analysis software can be used to select the network of flows of goods and of economic relationships, directly or indirectly affected by CIM technology diffusion. This network could be the base, for instance, of a system dynamics framework, used for different scenario simulations.

Among these three alternative modeling approaches we adopted the second one. An aggregated econometric input-output model will be proposed which includes some decision rule to explain the further dynamics of the share of CIM technologies in the output of different sectors of the economy - first of all of the metalworking industry.

Tchijov [1987] carried out a diffusion study for NC-machines in the U.S. metalworking industry. Therefore in the present chapter, a model of the U.S. economy will be proposed to continue this research. Since Tchijov referred in his study to the 2-digit subdivision of the U.S. metalworking industry, the same classification is used in the econometric input-output model of the U.S. economy discussed here.

The following table contains the preliminary sectoral classification of the model, the metalworking industry (MWI) has been kept at the 2-digit level, while other sectors of the economy were aggregated. This subdivision of the MWI is the same as in Kinoshita/Yamada [1988].

Table 2 - Sector Classification of the Model.

No.	Identification	Sectors of the 85-sec. I/O-Table	
1	Agriculture/Forestry	1-4	
2	Mining	5-10	
3	Construction	11-12	
4	Other manufacturing	13-38,64	
5	Final metal products	39-42	
6	Non-electr. machinery	43-52	Metal
7	Electrical machinery	53-58	working
8	Transport equipment	59-61	industry
9	Instruments	62-63	
10	Transport/Warehouses	65	
11	Communications	66	
12	Services/Other ind.	67-68,70-79,81-84	
13	Trade	69	
14	invent.Val.Adjustm.	85	
15	Non-comparable Import	80	

As is the practice in econometric modeling, we use different approaches to link an input-output framework with the production function apparatus. One of the problems to be solved by such a linkage is that both input-output and production function to a certain extent perform similar operations, calculating output from production factors or vice versa.

Traditional input-output analysis is connected with the calculation of gross output by industry from final demand by the delivering industry. The circle could be closed by behavior equations explaining final demand components of wages, profits, disposable income and other factors, depending on their part from gross or net output by sector.

In this context production functions (PF) by sector would actually duplicate an already existing feedback circle, and they would not make sense, if used for the calculation of output depending on production factors like, e.g., labor and fixed assets. Some econometric input-output models do not use PF at all (see, for instance, Almon et al. [1974] and Levitskij [1977]).

There are two basic concepts to cope with this issue:

(a) to make the PF compete with the I-O framework within a disequilibrium model (e.g. Uno [1987]);

(b) to reverse either the I-O system or the PF to connect one to the other.

In the second case, the production functions could be used, for instance, for computing labor demand from net output and capital stocks instead of calculating output from factors (Klein [1983]). Another approach is based on the reversion of the input-output part of the model. This can be done, e.g., by calculating final deliveries from gross output (Welfe [1983]).

A different concept is used by Höschel [1985]. In his model deliveries of materials to each sector are calculated with the help of a distribution share matrix. This matrix was obtained on the base of an input-output table, simply dividing the shipments of every producing industry to each sector by the sum of deliveries of this industry. The sum of materials by the purchasing sector together with stocks of gross fixed assets enters the production functions by sector.

The comparison of these different approaches is illustrated in figure 6. The structure of the models is simplified extremely to show only the principal differences. Important details are omitted.[2]

For the purposes of macroeconomic impact analysis of CIM technologies the concept of Klein seems to be the most suitable, mainly for two reasons:

(a) this model in its "classical", demand- oriented form. So multiplier effects appear in a similar way as in Leontief's dynamic models.

(b) The production function is used for calculating labor demand by sector. Thus the results obtained by S. Mori [1987] and A. Tani [1988] applying the production function apparatus to explain robot diffusion can be utilized immediately.

A possible version of the structure of such a model is described in Fig. 7, which shall be discussed now in brief.

The key part of the model is an aggregated Input-Output table with a sectoral classification (Table 2). It is used to transform final demand by producing sectors into net output by sector. With the help of investment functions by sector, gross fixed investment is calculated on the basis of net output. Now changes in capital stock can be determined. Capital stocks together with net output will enter production functions by sector to compute labor demand by sector.

The non-investment part of final demand, by using sector and capital goods not delivered by the metalworking industry, will be obtained using very rough estimates. For this purpose, e.g., "bridge vectors" could be used to calculate these values from GNP or from gross fixed investment as a whole.

Deliveries of capital goods by metalworking sectors must be determined by more sophisticated methods. In Fig. 7, one possible approach is demonstrated - the use of matrix B to transform investment for new equipment by sector into demand for equipment by the supplying industry.

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[2] The comparison of different econometric models is a rather interesting subject of research. Valuable findings in this field have been obtained, e.g., by Fromm [1973], Klein/Burmeister [1976], Chirinko/Eisner[1983], Salinas/Weyant [1987] (comparison of main U.S. models) and Garbely/Gilly [1984], Boutillier [1984] (using structural analysis methods for econometric model comparison.

As the first step, matrix B can be determined on the basis of a "capital flow table" as usually published in connection with input- output tables.

Technological change due to the penetration of CIM technologies is represented here in a way proposed by Carter [1987]. Some formal investment decision rule is used to decide between investment in old and new technologies depending on expected returns.

After obtaining the share of investment in new technologies x(j) by sector the corresponding column of matrix B is being modified. Now following the changes of the vintage structure of capital stock one can find out the share of the new technology in sectoral output a(j). The latter will allow us to modify both matrix A and the production function (i.e. the labor demand function).

As a precondition for this approach in all three cases - A and B matrices and production function by sector - two data sets must be created: for old and new technology. A special problem will be the specification of the decision rule, which must be able to explain and to predict technological diffusion. In any case this block of the model can be replaced by some "scenario generator", possibly interactive. Yet, technological change via CIM technologies will probably also affect other variables and relationships even in this relatively simple framework - e.g. inventory change as a part of final demand or investment functions. During the summer of 1988, on the basis of the 85-sector input- output tables of the *U.S. economy* for 1972, 1977, and 1981, different aggregated I-O tables were calculated. Main data flows are shown in Fig. 8:

1. The 13-sector "Use' matrix was aggregated from the detailed Use table without any other transformation. For this table all changes in aggregates can be traced back to detailed data.

2. The 85-sector industry/industry table was calculated from detailed Make and use tables according to Leontief/Duchin [1986]. Afterwards the table was aggregated and deflated. Value added and total output deflators were approximated from different sources. This table can be used in a model as described above.

3. Product chain analysis information about technological relationships between commodities is also desired. Such a commodity/commodity table can be obtained with the help of standard SNA methodology. In this case, the industry technology assumption was used to circumvent problems with negative matrix elements, e.g. Almon (1986) Stahmer (1984).

While the work on this model is still incomplete, nevertheless, it is possible to draw some conclusions regarding further research on this subject at IIASA, and we offer the following conclusions in the next section.

Conclusions

1. Input-Output analysis, especially if combined with econometric analysis of additional economic relationships, can be considered as a feasible and productive approach to the study of macroeconomic impacts of computer integrated manufacturing and related technologies.

   With the help of these tools it becomes possible to examine not only direct impacts of new technologies on the economy but induced changes and farther, indirect consequences mediated by interindustry and other relationships as well.

2. One of the main problems of model based macroeconomic technology assessment is the synthesis of relatively aggregated macroeconomic analysis and the inevitably more detailed description of the new technology, its backward and forward linkages, its expected penetration and cost/benefit behavior.

   The choice among different possible approaches to this synthesis will be determined, above all, by the aims of the analysis, and there is an increasing role of government science and technology policy both in market and centrally planned economies.

3. The success of previous studies on input- output based macroeconomic impact assessment of CIM technologies to a great extent was predetermined by
    (a) the existence of an already "established" model frameworks that could be adjusted to this particular subject of analysis and,
    (b) the accumulation of knowledge and data about CIM technologies and their diffusion.

This conclusion is important for further research at IIASA. The considerable stock of expert knowledge and international data on CIM technologies provides a valuable base for macroeconomic impact studies.

Possible application areas could be, for example:

(a) providing scenarios of CIM technology diffusion for impact simulations by external collaborators and closer cooperation with experienced modeling teams in the IIASA member countries.

(b) continuation of the preparation of international comparable labor matrices and comparative analysis of this data.

(c) international comparison of unified indicators of CIM technology diffusion on the macroeconomic level, with special respect to further development of the international division of labor in this field.

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Abbreviations: SCB - Survey of Current Business

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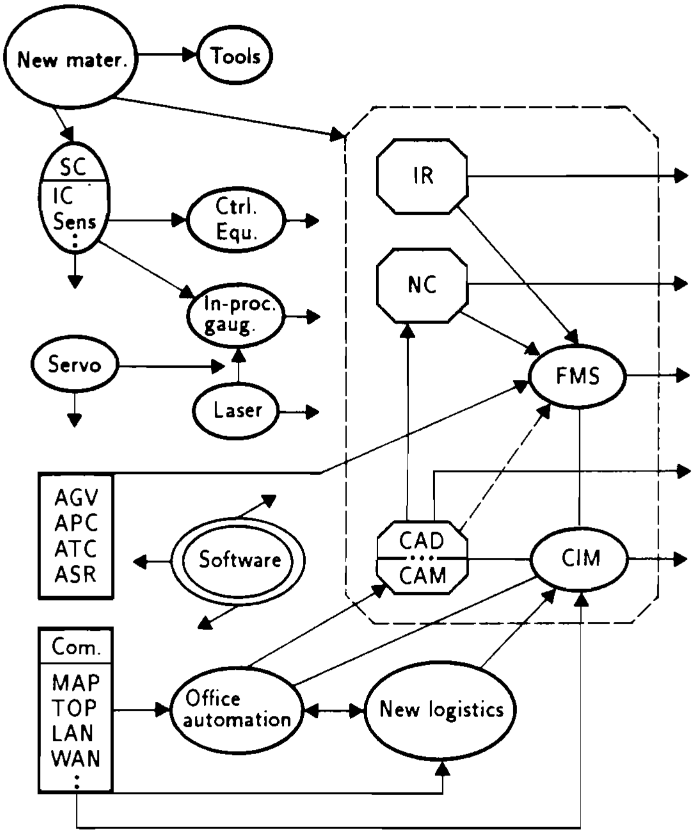

Figure 1. Components of CIM Technologies.

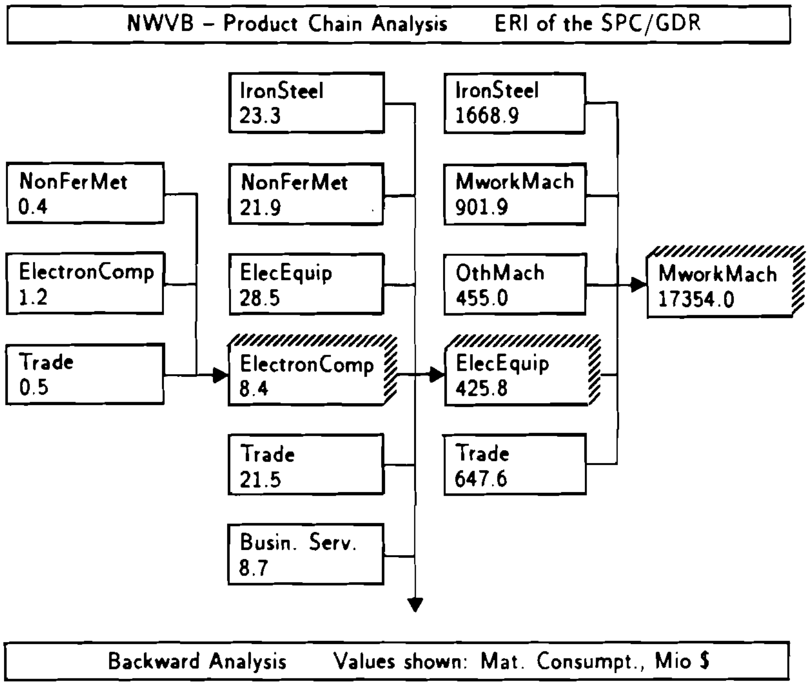

Figure 2. **Backward Analysis.**

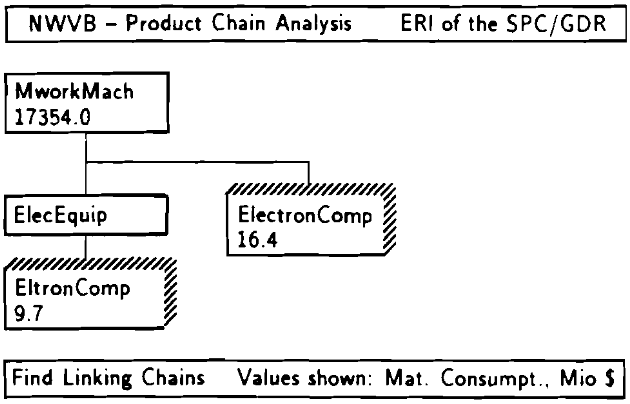

Figure 3. **Analysis of Linking Chains.**

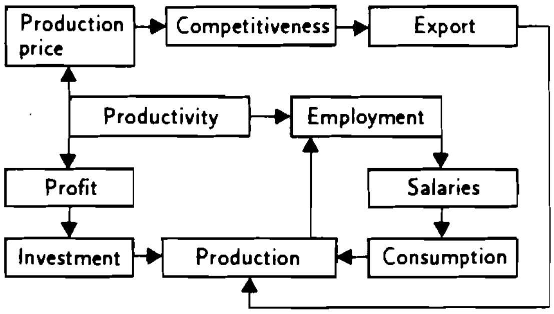

Figure 4. **Network Effects of FMS. Source: Bonetto (1985).**

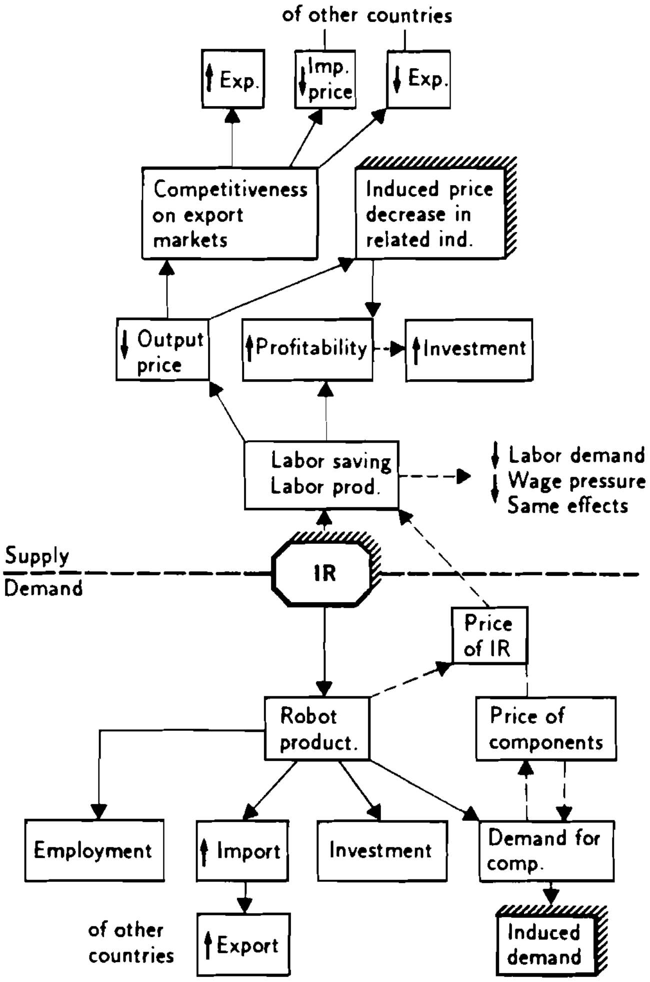

Figure 5. **Causal Chains of Robot Impacts. Source: Kinoshita & Yamada (1988).**

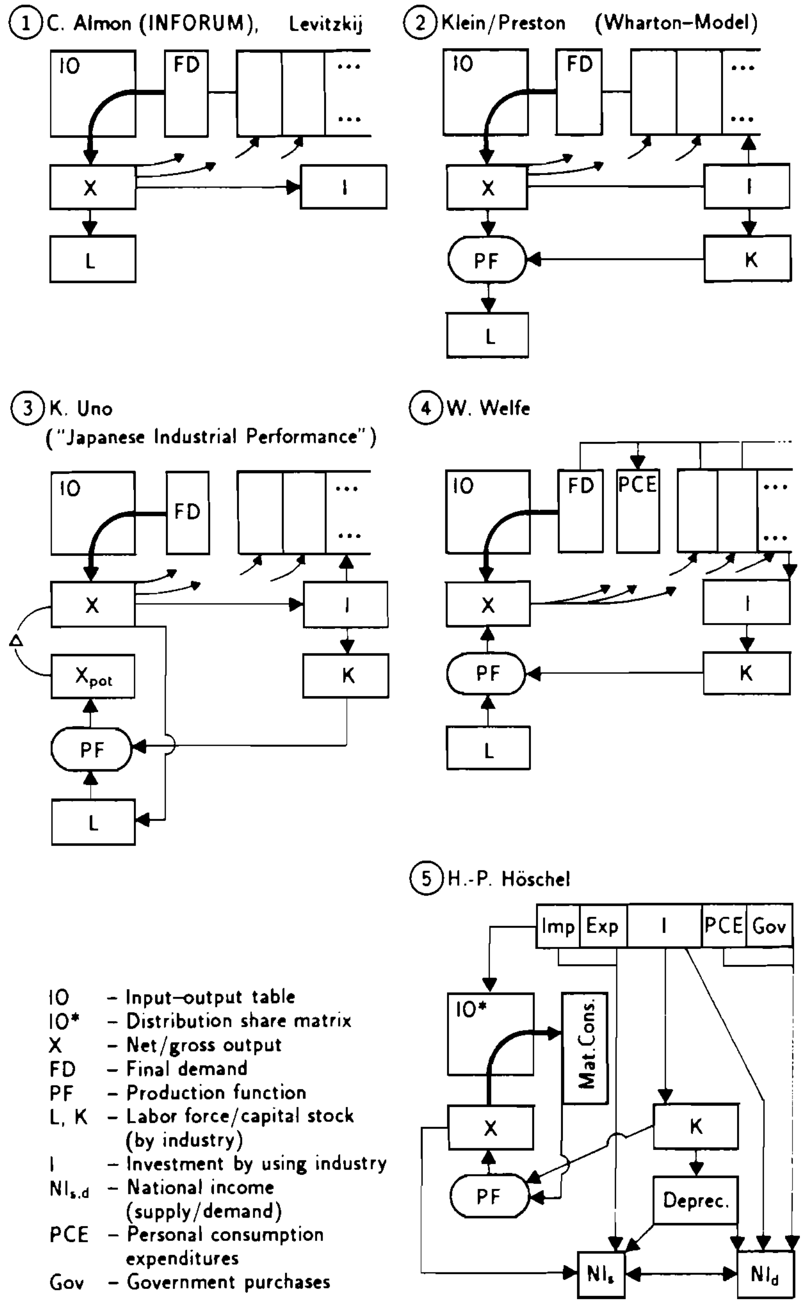

Figure 6. **Input-Output Models with Econometric Equations. Sources: Almon (1986); Klein (1983); Uno (1987); Welfe (1983); Höschel (1985).**

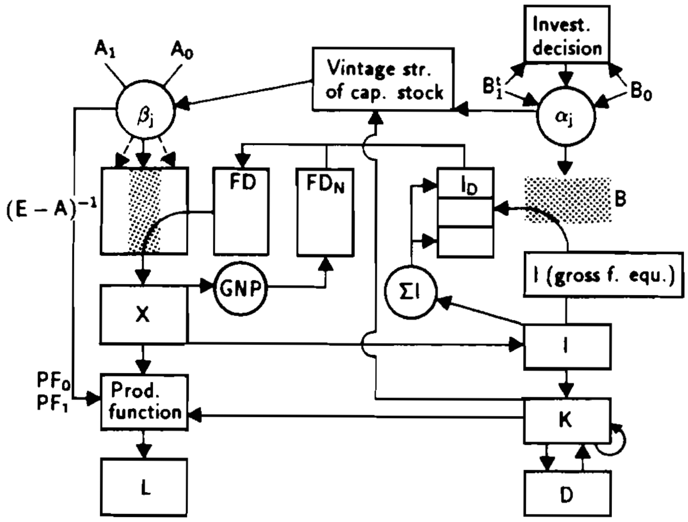

Figure 7. Thirteen Sector Input-Output Model of the U.S. Economy. Macroeconomic Impact Analysis of CIM Technologies.

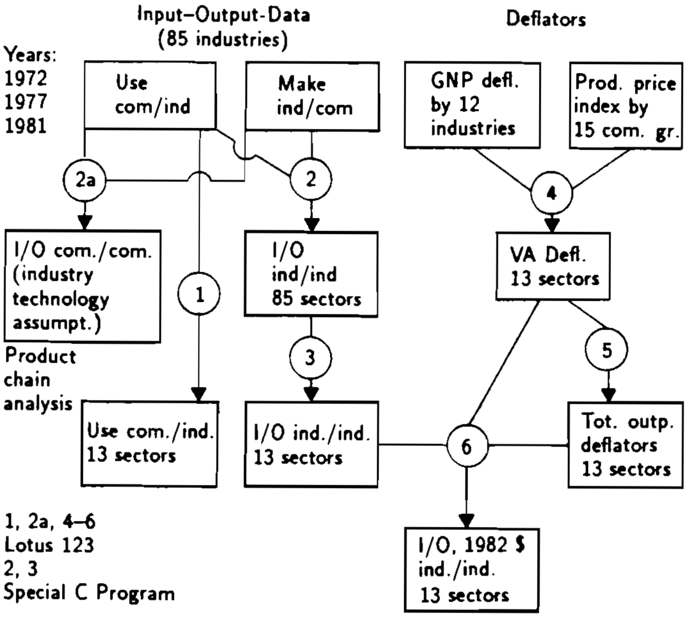

Figure 8. Calculations Performed on 85 Sector Input-Output Tables of the U.S. Economy.

3. CIM DIFFUSION

The International Diffusion of Computer Aided Design

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1. Introduction.

One purpose of this paper is to compile data on the use of Computer Aided Design[1] in different countries. CAD has the potential for automating the design of discrete parts. The use of CAD and other CIM technologies such as robots and numerically controlled machine tools is having a profound impact on productivity and labour. The use of these type of technologies may thus partly explain economic performance.

A second issues is what the relevant factors are that affect the use of CAD. Knowledge of these are important for policy-makers in designing appropriate policies.

A third question addressed in this paper is the design of a government policy to promote the use of CAD. Realizing that CAD may be important to the future competitiveness of manufacturing industries, governments have embarked on programmes to raise the level of usage. These programmes have primarily been devoted to disseminate information. However, a *low* level of use may be the appropriate considering the conditions pertaining for the potential adopting industries. Policy intervention may then be unnecessary. There are also other government policies to be considered, eg changing capital cost.

2. Theoretical framework.

Six propositions are made. Each variable is named in brackets in each proposition.

It is assumed that firms are economic organizations which adopt technology to increase profitability. If a firm tries to produce each possible output level at the lowest possible cost this implies that a firm adjusts its input mix until the technologically determined marginal rate of technical substitution equals the price ratios for those inputs (Binger & Hoffman, 1988). Thus, the higher the cost of labour to the cost of capital the higher is the propensity for firms to use CAD[2].

P1: The use of CAD is a positive function of the cost of engineering labour (LAB) and a negative function of the cost of capital (CAP).

The proposition is based on the standard microeconomic assumption that information about technology is equally and costlessly available instantaneously for the whole population of potential adopters (Binger & Hoffman, 1988), This is not a viable assumption in studies on international diffusion (Stewart, 1978). There exist information asymmetries between potential adopters (Kling,1981; Nabseth,1973) as well as asymmetries in the availability of a technology. As noted by Webster (1979) the industrial buying decision is strongly affected by buyer-seller interaction. In the case of CAD the need for interaction with sales agents, service and after sales support may be even more pronounced due to the complexity of the technology, the difficulties in installing and supporting CAD (Ederle et. al., 1987),

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[1] CAD denotes the elaborate preparation of complex schematics and blueprints with computers. This does not include CAM (Computer Aided Manufacturing). Due to the difficulty of combining different systems with different, often proprietary, communication protocols, few installations are of the integrated CAD/CAM type (Hoarse, 1986). In the USA, 39% of the establishments used CAD and 17% used CAD output to control manufacturing (US Department of Commerce, 1989). It is not known how many of these are digitally integrated.

[2] Labour cost savings is the most cited reason for adopting CAD (Arnold, 1984; Edquist & Jacobsson, 1988). The average price per CAD seat has decreased from $80.000 in 1979 to $20.000 in 1986 (Hayashi, 1987). The size of the investment is by now relatively small and capital costs may, in effect, not affect the amount of CAD used by firms.

as well as the need for educating the users (Ebel & Ulrich, 1987; Simmonds, 1988). The US industry has for a long period been the major supplier of the technology[3]. It is proposed that:

P2: The use of CAD is positively associated with increased availability of the US supplier industry. (SUPPL)[4]

The resources of the US supplying industry was limited and it therefore chose target markets (Kaplinsky, 1982). Larger national markets would be preferred to smaller if the fixed costs of sales to any market is approximately the same, since a large market would have a larger potential sales volume to spread the fixed sales and support costs on. Since CAD was only to a limited extent, usable outside the aeronautics, automotive and electronics industries in the beginning of CAD technology's evolution, the size of these three industries together are probably of importance to the sales efforts, and concomitant sales, in a country.

P3: The use of CAD is positively associated with the size of the natural potential user industry. (SIZE)

Theoretical models on the relation between industry structure and diffusion are inconclusive (Stoneman, 1983, p. 102). From a game-theoretical perspective, Reinganum (1981) show that if demand is linear an increase in the number of firms will cause most firms to delay adoption. No clear empirical evidence on the sign of the relation between industry structure[5] and rate of diffusion has been found (Romeo, 1975; 1977, Davies, 1979; Kling, 1981). Other measures of competition, where international competition is considered, may perform better. Schmalensee (1989) report that the ratio of imports to domestic consumption tends to be negatively correlated with the profitability of domestic sellers, especially when domestic concentration is high. Significant coefficients of varying sign between export ratio and profitability of the domestic industry have also been reported (Schmalensee, 1989). Kling (1981) found a positive relation between the speed of diffusion and the export share of production in the adopting industry.

In later years international competition from Japanese and other low input cost countries has been increasing (Florida & Kenney, 1990; Jacobsson, 1986). Domestic firms, which may also engage in X-inefficiency (Leibenstein, 1979), may thus be inclined to speed up the adoption of productivity enhancing techniques. With a higher degree of international competition the firm would probably exhibit a larger need for productivity improvement by adopting CAD. On the other hand, if there is intense competitive pressure the profit margin is probably low and the willingness to invest in new technology may be discouraged. We will however argue that:

P4: Industries which are subject to international competition will use CAD more. (INT)

Firms have unequal resources. Firms with a higher expertise may be more capable to gather, evaluate, assimilate and apply information and thus earlier to adopt. This proposition is also advanced in Cohen & Levinthal (1989) who argue that firms invest in

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[3] The industries in the UK and France are the two second largest suppliers. These have primarily served the domestic markets (Arnold, 1984).

[4] The argument can also be reversed. The more CAD the supplier industry sells in a specific country the higher is the demand from customers to have support available. The presence of the US supplier industry in this country would probably be relatively higher than in other countries. The above measure can not distinguish between the two opposing explanations (technology push or demand pull).

[5] Number of firms and the variation of the log of firm size.

R&D not only to pursue innovation but also to develop and maintain their broader capabilities to assimilate and exploit externally available information. It has been found that establishments which perform R&D on site have a higher incidence to use CAD (Gibbs & Edwards, 1985; Rees, Briggs & Hicks, 1985).

P5: There is a positive association between high expertise[6] in an industry and the use of CAD (R&D).

Finally, Mansfield (1973) argues that the general level of education in each country (as well as the scientific level), is important in determining the rate of diffusion. The higher the general skill in the adopting firm the lower will the adaptation and implementation cost be[7]. Firms with higher skill level will thus have lower costs and can adopt more CAD or adopt earlier (when equipment is more expensive).

P6: Countries with higher levels of education use CAD more. (EDU)

The selection of variables to be studied represent some, but by no means all important variables that can affect the use of CAD. Two important variables are barriers to trade and growth of domestic production capacity. If there are barriers to imports one would expect domestic diffusion to increase with an increase in domestic supply (Swan, 1973). Although there might be barriers to trade in the case of CAD these have been found very difficult to measure. However, the availability of the US supplier industry in each country is to some extent capturing this variable. The USA has been by far the major supplier of CAD until the last three years , and increases in the domestic supply during the relevant time period is for most countries insignificant.

3. Data and Measurement.

Data on the number of CAD seats in each country has been collected from a number of sources. In some cases data is from surveys of users, in others sales data is provided from suppliers. When data is provided from suppliers, small supplying firms are often excluded. Some suppliers have also refused to provide sales figures. Data may thus be biased downwards. However, this bias is considered to be small, in the order of 1-5%. It has not been possible to fully account for the scrapping of equipment. Thus, the figures may be biased upwards, especially when sales data from suppliers is used. The bias would tend to overestimate the stock for large user countries, especially for the USA, where only sales data from the suppliers was available (see Table One).

The reliability of the data has been compared against as many independent sources as possible and cross-checked to be consistent over time. The estimate and sources judged to be the most reliable are reported[8]. Data varies considerably with respect to its validity. It is common to report the use of CAD by type of system, for example by PC-, workstation-, mini- and mainframe computers. However, sometimes only 'systems' are reported. In the light of the vast diffusion of PC and workstation based CAD this would be an erroneous descriptor of the diffusion of CAD. Efforts have thus been made to recalculate reported

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[6] This may also be an indicator of the size of the potential market. The more R&D resources that are used the more product developments there are, and the larger is the potential for the installation of CAD equipment.

[7] It has been noted that the main skill requirements are 'computer literacy' and higher mathematical and analytical skills when adopting CAD (Ebel & Ulrich, 1987).

[8] Due to space limitation estimates of bias for each source are not provided. Readers may contact the author for estimates.

figures of system installations to seats. A CAD seat is a design engineering workplace, equal to one visual display. A survey of 28 CAD system suppliers revealed that the number of seats per system averaged 3.54 in 1983 (elaboration on data from Daratech, 1984). Other sources use four as the average number of seats per system (Arnold, 1984; Edquist & Jacobsson, 1988). In this study four seats per system has been chosen. In some instances data from the suppliers are given. In those cases, Daratech (1984; 1987) provides conversions of seats per each type of system to give a more accurate estimate on total number of seats installed. For Japan, seven seats per system were used (survey of 82 large engineering firms by Yano Economic Institute, 1987). This tendency for the use of larger systems in Japan is due to the extensive use of Japanese mainframe computers, and also to the specific division of labour between engineers and drafters in Japan (Hayashi, 1985). Finally, the total number of seats have been derived by summing the number of system seats, workstations and PC-packages.

In Table One data on the cumulative number of CAD seats are presented. It is seen that the number of installed seats increased considerably during 1984 to 1986. As hypothesized the largest proportion of the seats are installed in USA. In 1985 63% of the world population of seats were installed in the USA. France and the UK have, as suggested earlier, installed a large proportion of the remaining number of seats. A very small fraction, less than 2%, is installed in the developing countries whereof the installations in Taiwan represented one half. Similarly a very small fraction, 1%, is installed in the state planned economies.

Table 1. The Diffusion of CAD in 21 Countries.

Year	USA	UK	FRG	FRA	ITA	JAP	YUG	SWE	ROC	IND	ARG	BRA	NOR	SIN	FIN	DEN	ICE	BUL	USSR	TAI	CAN	WORLD
76						160																4000
77					120	150																5200
78					170	320																6900
79	7150				260	730		240														9000
80	9900		400		410	1120		360	20													17600
81	14000	1660	1230		580	1530		550	40											190		28800
82	35800	4000	1500	2250	800	2900		820	80		40	60	280							350		47000
83	44100	10000	11000	10000	890	5300	100	1340	130	100	70	110	360					0		650		60000
84	54400	13000	16000	12000	1000	9100	130	2200	250	200	90	190	450	200				60			2000	76000
85	132200	17000	21000	14000	1500	10400	250	3620	430	390	190	340	900	290	630	750	20	120	770	1300	5000	211100
86	210000	23000	26000	16000				5880	740	770					1260	2200	30	170	1000			303000
87		31000																230	2300			
88		56000																290			10000	

Sources: **USA**: 1979-1981: Computerworld, April 6, 1981 (IDC), 1982: Daratech (1983), 1983: linear interpolation: 1984: Daratech (1984), 1985: linear interpolation, 1986: Daratech (1987). **UK**: 1981-82: Arnold (1984), 1983-1988: Northcott & Walling (1987). **FRG**: 1980: Arnold (1984), 1981: Arnold (1984) + own estimate, 1982: Arnold (1984), 1983: Northcott, Rogers & Knetch (1985), 1984-85: linear interpolation, 1986: CADCAM International, Dec. 1988. **FRANCE**: 1982: Arnold (1984), 1983: Northcott, Rogers & Knetch (1985), 1984-85: linear interpolation, 1986: CADCAM International, Dec. 1988, **ITALY**: 1977-1982: Computer Age-World Trade, July, 1983, 1983: linear interpolation, 1984: The Engineer (1985), 1985: Grumman International (1986). **JAPAN**: 1976-1985: elaboration on Japan Electronic Almanac (1988) and Yano Economic Institute (1987). **YUGOSLAVIA**: 1983: Edquist & Jacobsson (1988), 1984-85: extrapolation based on growth of world population. **SWEDEN**: 1979: Carlsson & Selg (1983), 1980-81: linear interpolation, 1982: Lindeberg (1983), 1983-85: linear interpolation, 1986: SIND (1987) for workstations and added estimate of total PC-CAD population based on a 50% market share of Autodesk installations (Autodesk AB, 1988). **KOREA**: 1980-83: Edquist &

Jacobsson (1988), 1984: Kim (1986), 1985: linear interpolation, 1986: Kim (1987). **INDIA**: 1983, 1986: Edquist & Jacobsson (1988), 1984-85: linear interpolation. **ARGENTINA**: 1982-83: Edquist & Jacobsson (1988), 1984-85: extrapolation based on growth of world population. **BRAZIL**: 1982, 1985: Edquist & Jacobsson (1988), 1983-84: linear interpolation. **NORWAY**: 1982: Arnold (1984), 1983-84: extrapolation based on growth of world population, 1985: extrapolation based on growth of world population, comparison with estimate of total PC-CAD population based on a 50% market share of Autodesk installations (Autodesk AB, 1988). **SINGAPORE**: 1984-85: Edquist & Jacobsson (1988). **FINLAND, DENMARK, ICELAND**: 1985: extrapolation based on growth of world population, 1986: estimate of total PC-CAD population based on a 50% market share of Autodesk installations (Autodesk AB, 1988). **BULGARIA**: 1984-87: linear interpolation (no installations before 1984), 1988: Mateev (1988). **USSR**: 1986-87: Pravda 1986-01-26, 1987-01-18, 1988-01-24. **TAIWAN**: 1982, 1984: elaboration on Edquist & Jacobsson (1988) and Machinery Industry, Sept, 1987 (in Chinese), 1983: linear interpolation, 1985: extrapolation based on growth of world population. **CANADA**: 1984: elaboration on Mackay (1984), Scrimgeour (1988) and Daratech (1987), 1985, 1988: estimation from Evano Research Inc., Canada (1988). **WORLD:** 1976: AEU, June 1982, p. 145 (Predicast), 1977-78, 81, 83: linear interpolation, 1979: Computerworld, April 6, 1981 (IDC), 1980: Kaplinsky (1982) and own estimate of the stock of IBM seats (=400), 1982: Daratech (1983), 1984: Daratech (1984), 1985: sum of all countries,1986: Daratech (1987).

We continue by describing the level of penetration of CAD by number of employees in manufacturing in 21 countries (in 1985). These are exhibited in Table Two. The table shows that USA is by far the leading user of CAD with a penetration of 6.33[9]. Note however that this may be overestimated compared to other countries. Sweden stands out as the second largest user of CAD. Leading industrialized countries then cluster in the range of 3.17 to 2.62 penetration. Smaller industrialized countries (Finland, Denmark, Iceland) and a cluster of newly industrialized countries (Singapore, Japan & Taiwan) follows. The laggards consist of Italy[10] , newly industrialized and state planned economies. State planned economies together with developing countries have a very low penetration level.

The low penetration of CAD in Italy and Japan is notable as well as the relatively high penetration in Argentina compared to fellow developing countries. The penetration in Sweden and Norway are also considerably higher than its fellow Nordic countries. In general, a high penetration exists in the industrialized countries with the exception of Italy and Japan, and a very low level in developing and state planned countries with the exception of Argentina.

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[9] If we assume that CAD equipment has an economic life-time of five years and thus deflate the yearly sales in the USA by 20%, the penetration was 5.17 CAD seats per thousand employees in 1985.

[10] Data for Italy was given from three independent sources. Mariotti (1988) reported 54 CAD/CAM systems in the metalworking industry in 1984, The Engineer (1985) 250 CAD/CAM systems in 1984 in Italy and Grumman International (1986) 1500 workstations in 1985. The figures validate each other. Nothing indicate a penetration of around 10000 seats which would be comparable to France and West Germany.

Table 2. The penetration of CAD seats in the manufacturing industry.

Country	CAD per employees[1] (per thousand)
USA	6.33
Sweden	3.76
UK	3.17
France	2.89
Norway	2.59
West Germany	2.62
Canada	2.30
Denmark	1.85
Finland	1.27
Singapore	0.99
Japan	0.72
Iceland	0.67
Taiwan	0.52
Italy	0.31
Argentina	0.22
Korea	0.13
Yugoslavia	0.11
Bulgaria	0.08
India	0.06
Brazil	0.05
USSR	0.02

[1] Source: Yearbook of Labour Statistics, ILO, 1988, Statistical Yearbook of the Republic of China, 1986, Table 1. In thousands.

The measurement of variables are described in Table Three. The result in Section Three has been featured by relative (normalized) measures of (penetration of) CAD, SUPPL, R&D, and SIZE as described in Table Three, but have also been examined on absolute scales. There are two explanations for using normalized scales. First, we want CAD to be measured as a ratio of the potential market level. By using normalized scales the effect of market size on other variables can in part be avoided. Secondly, effects from variations in exchange rates, which have been extremely large during the eighties, can be avoided by normalization.

Table 3. **Measurement of variables.**

Variable	Operationalization
CAD penetration (CAD)	number of CAD seats/ number of employees in ISIC 3_i (1985)
cost of labour (LAB)	total cash earnings per working hour$_i$ (1983)
cost of capital (CAP)	mean short term interest rate 81-85$_i$
availability of supplier industry (SUPPL)	# sales offices$_i$/total # sales offices
market size (SIZE)	value added ISIC (383+384)$_i$/value added ISIC 3_i (1983)
expertise in adopting industry (R&D)	R&D expenditure ISIC (383+384)$_{[i]}$/value added ISIC (383+384)$_i$ (1983)
international competition in adopting industry (INT)	export ISIC (383+384)$_i$/ production ISIC (383+384)$_i$ (1985)
skill level (EDU)	% of population over 25 with university education$_i$ (1980)

Notes: i=specific country. ISIC 383=electrical machinery, ISIC 384=transport equipment, ISIC 38=metalworking industry, ISIC 3=manufacturing industry. **Labour cost**: Assumed 200 working hours per month for Japan, Yugoslavia, Korea, India, Bulgaria and USSR. **Capital cost**: Lending rate to meet short- and medium term financing needs of the private sector except Argentina where deposit rate was used and Brazil where bank rate, end of period, was used. **Number of sales offices**: Information from 79 US, 1 British and 1 French company. **Value added**: Data in national currency for 1983 except Italy (1982), India (1982), Argentina and Brazil (1980 and US$), Denmark, Iceland and Canada (1982). **R&D**: 1983 US$ except Italy (1982), Korea (won), India (1984/85 and rupees).**Export and Production**: 1985 US$. SITC 716+76+77=ISIC 383, SITC 78+79=ISIC 384 for Yugoslavia, Korea, India, Argentina, Brazil, Singapore, Canada and FRG. *Sources*: **Exchange rate**: Annual Review of Engineering Industries and Automation, United Nations, Vol 2, 1988. **Labour cost: Yearbook of Labour Statistics**, ILO, 1981. **Capital cost**: International Financial Statistics, IMF, June 1988. **Sales offices**: Daratech (1984). **Value added**: Industrial Structure Statistics, OECD, 1986; Industrial Statistics Yearbook, United Nations, 1985; Industry and Development, Global Report, UNIDO, 1986 (Argentina and Brazil); Handbook of Statistics, CEI, 1987, p. 353 (India). **R&D**: OECD/STIID databank, OECD, 1988; Report on Industrial Cencus, Economic Planning Board, Korea, 1983; Research and Development Statistics 86-87, Department of Science and Technology, New Dehli, 1988. **Export and Production**: Annual Review of Engineering Industries and Automation, United Nations, Vol 2, 1988; Industrial Structure Statistics, OECD, 1986; International Trade Statistics Yearbook, United Nations, 1985; Industrial Statistics Yearbook, United Nations, 1985; Handbook of Industrial Statistics, UNIDO, 1988. **EDU**: UNESCO Statistical Yearbook, UNESCO, 1986.

4. Result

In Table Four the results of a pairwise Pearson correlation is displayed. The variables are measured as displayed in Table Three. Separate measures of LAB and CAP are included as well as the hypothesized relation between labour cost and capital cost (LAB/CAP). This makes it possible to discern the separate impacts of the input factor costs.

Table 4. Correlation matrix and number of observations.

	LAB/ CAP	LAB	CAP	SUPPL	SIZE	R&D	INT	EDU	CAD
LAB/CAP	1.00								
LAB	.88**	1.00							
CAP	-.40	-.36	1.00						
SUPPL	.23	.33	-.08	1.00					
SIZE	.03	-.11	-.18	.19	1.00				
R&D	.25	.34	-.19	.54*	.61*	1.00			
INT	.38	.49	-.30	-.36	-.10	-.28	1.00		
EDU	.61*	.72**	-.19	.56*	.10	.25	.15	1.00	
CAD	.54*	.77**	-.31	.70**	.27	.78**	.09	.71**	1.00
LAB/CAP	16								
LAB	16	18							
CAP	16	16	20						
SUPPL	16	18	20	21					
SIZE	16	16	20	20	20				
R&D	13	13	15	15	15	15			
INT	16	16	19	19	19	15	19		
EDU	13	14	16	17	16	11	15	17	
CAD	16	18	18	21	18	14	17	15	21

Note: Pairwise correlation was chosen due to lack of data.

* Significant at 0.05 level.

** Significant at 0.01 level.

The table displays expected signs of all the proposed relations. Five variables were significantly correlated with the use of CAD: labour to capital cost relation, labour cost, availability of the supplier industry, R&D intensity in the potential user industry, and level of education of the labour force[11]. In the light of the very crude measures of the variables and the low number of observations the result is surprisingly good.

The relation between the capital to labour costs ratio and the use of CAD is driven by labour costs as shown in the bottom row of the three first columns in the correlation matrix. Thus, we expect countries with high labour costs to have a high penetration of CAD. Capital costs failed to reach a significant relation although the sign is as expected.

The availability of the supplier industry, SUPPL, is significantly correlated with CAD as proposed. It is also related to R&D and EDU. The correlation with EDU may be attributed to the extreme number of sales offices in the USA (69% of world population, second highest observation has only 2%), together with the second highest educational level. This national observation is to a large extent driving the relationship. The relationship between R&D and SUPPL is more robust[12]. It may be that the supplier industry choose to focus

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[11] When the logarithm of the absolute measures of the variables SUPPL, SIZE, R&D and CAD were used all the proposed relationships increased in significance. The correlation coefficients for the bottom row of the matrix were, from the left, .617, .693, -.548, .886, .906, .961, .169, .715, 1.000.

[12] When USA was deleted the correlation coefficient for the relation between SUPPL and EDU was halved, whereas it increased for the relationships between R&D and SUPPL and CAD and SUPPL.

their resources in industries which perform a lot of R&D. The suppliers would then take the level of R&D as an indication of the market.

The density of the supplier industry in relation to the size of the natural potential user industry was uncorrelated to CAD (result not shown). It may be that the relation is going from installations of CAD to the setting up of sales offices, instead of the industry inducing sales (as measured by its 'density' in the natural potential user industry). Simmonds (1988), argue that the industry in effect has had difficulties in supporting its installations due to the large sales volume. This would support the assertion above that there has been a demand pull on the international market.

The correlation between SIZE and the use of CAD failed to reach significant correlation. In Figure Two the relation between market size and the penetration of CAD is depicted. The observations can be organized by two clusters. Both have a positive association between the penetration of CAD and market size, but at different levels of penetration and with different coefficients. Singapore, Japan, Italy, Korea, India, Argentina, Yugoslavia and Brazil form one cluster. Other, industrialized countries form another. The variations within these two groups are low[13]. Some authors claim that developing countries are mostly pursuing a low cost/high volume strategy (Jacobsson, 1986). Since the use of CAD is more suitable for a product innovation/differentiation strategy than for a low cost strategy this is reflected in Figure One. When absolute measures of the variables were correlated a very high relationship was found (see footnote 11). We would thus be reluctant to reject the proposed hypothesis although the relation is not as clear cut as originally proposed.

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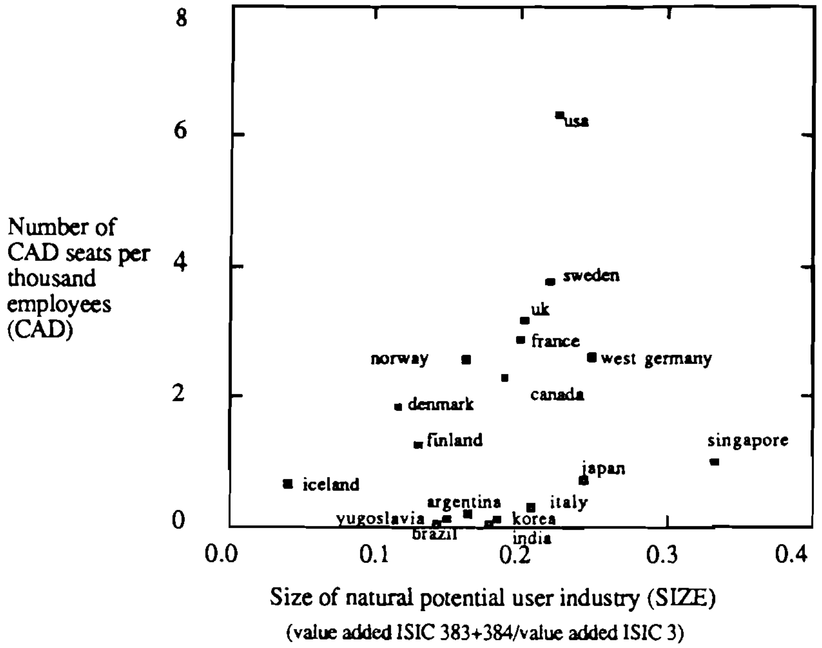
[13] Also note that if the observation from the USA is deflated with respect to scrapping of equipment the pattern would improve. This feature held true for all other correlations as well.

Figure 1. The relation between size of market and penetration of CAD.



The variables R&D and EDU both had strong associations to the penetration of CAD. Since both measures are indicators of expertise in firms a conclusion would be that the level of education is a strong denominator for the use of CAD. R&D intensity may however, as discussed before, also be an indication of the size of the market. This is reinforced by the notable positive correlation between SIZE and R&D intensity.

In sum, we have seen that the size of the potential market varies between the different countries by the measures SIZE, R&D and LAB (the labour costs defines the possibility for substituting labour with CAD). The possibility of filling the potential market seem to be restricted. A low level of firm expertise may restrict the use of CAD. Furthermore the availability of information and knowledge, not only through internally developed expertise, but also that conveyed from the supplier industry, seem also to be important determinants of the use of CAD. The data suggests that the availability of the technology is not equal and that this restricts the possibility of countries to fill their potential market.

5. Policy Implications.

This study found that the diffusion of CAD has been unevenly distributed with a very high concentration in the USA followed by other industrialized countries. Developing and state planned countries had about one third to 300 times lower penetration. Government programmes aimed at increasing the use of CAD and other factory automation in industrialized countries seem not to be overly motivated considering the high level of penetration in these countries.

This study indicate that the major barriers to adoption of CAD are related to access of information and knowledge and to the ability of the potential adopters to gather, assimilate and apply this knowledge. This was also identified by the Ministry of Industry in Sweden (Carlsson & Selg, 1983; SOU, 1981). In 1981 the Swedish Government decided to promote the dissemination of information and knowledge on CAD by providing funds for the formation of CAD/CAM centers[14]. A total of 16 CAD/CAM centers have been in operation during 1980-87 in Sweden. The centers have had problems building up local knowledge and to keep equipment at the facility continually renewed to keep up with technological development. The centers have had difficulties in finding customers (Datavarlden, 1987; Giertz & Reitberger, 1989) and have probably had very little impact on the diffusion of CAD in Sweden.

A programme aimed at disseminating information should target firms with a low capability to evaluate information - such as small firms with a small stock of expertise[15]. However, given their low ability to assimilate information providing more information may not be the correct policy. What is needed is to improve their ability to assimilate new knowledge; their absorptive capacity. Sweden has a limited number of very large, internationally competitive, firms which are considered to be early adopters of new technology (Hörte & Lindberg, 1989). For example, in 1979 six of these firms accounted for 50% of the CAD installations (SOU, 1981). These firms have in turn a large network of smaller subcontractors who work in close cooperation with the large firms. In this case a programme aimed at improving small firm's absorptive capacity would probably benefit if channeled through relationships built up between these large and small supplier companies. The reason is that information transfer between such firms may be more effective than in the market[16]. Incentives may have to be devised for the large firms to channel information and knowledge further to their subcontractors although in principle it is in their self-interest to do so. Furthermore, it is also in the large firms self-interest to enhance the subcontractors absorptive capacity, so as to ensure that the subcontractor keep up with the pace of technological advance that the large firm is following. This is of course only one possible way of developing the absorptive capacity of small firms. Educational programs, R&D subsidies and educational cost subsidies are other alternatives.

For developing countries the situation is aggravated. Not only is information and knowledge about the technology scarce, but there is also limited availability of the technology. Edquist & Jacobsson (1988) mention that for a long time the US government applied an export embargo to India. In Korea there was a general lack of information about CAD, and a lack of trained personnel to use CAD. The presence of a supplier industry was low. In 1985 there were only five sales offices from the supplier industry in Korea and six in India. The problem of underprovision of the technology stems from the fact that there has been a monopoly supplier, the USA, and many recipient countries. The costs for disseminating the technology that will maximize social surplus diverge from what profit-seeking firms will expend. The technology tends to be undersupplied (Tirole, 1989). The

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[14] In 1979 all 60 CAD systems installed in Sweden were imported, there was no local production. Only four domestic firms provided services to help firms install CAD (SOU, 1981). A lack of locally available information and knowledge was perceived. A programme, aimed at sponsoring the diffusion of robots and CAD/CAM, had three intial aims: a) the formation of three engineering development centres (EDC) located at technical universities, b) the formation of three CAD/CAM centers as joint-ventures between universities and EDC:s, and c) increased funds for education and R&D at universities (Carlsson & Selg, 1983).

[15] An established fact is that small firms with low R&D are late adopters (see for example Kelley & Brooks, *this volume*). This is also implied by this study.

[16] The, by now, well-known argument of Oliver Williamson on the effectiveness of non-market mediated transactions can also be applied to less integrated, but still controlled, organizational forms.

recipient countries can form a coalition to pay a lump-sum to the supplier for the provision of adequate amount of goods, but free-rider problems among recipient countries induces each to try to avoid payment. Another possibility would be for each country to subsidize the supplier industry to set up sales offices and/or production in the recipient country. These are skilled to promote the dissemination of information and to facilitate the installations and maintenance of equipment and by definition delivers new technology. This study show that the use of CAD in a country was highly related to the number of sales offices in the country.

Yet another measure would be to promote the growth of a domestic CAD industry[17]. However, in developing countries labour is cheap and the firms mostly compete only in national markets. These factors reduce the demand for CAD. A further complication is that developing countries to a large extent depends on the licensing of foreign technology (Edquist & Jacobsson, 1988). The market for CAD in the engineering sector thus becomes substantially reduced since little design work is carried out. Since the domestic market may be too small the domestic industry would most certainly need to compete on the international market - this may require large subsidies.

Apart from trying to regulate the provision of information, knowledge and availability of the technology, the user can be stimulated to adopt by investment grants, subsidized leasing arrangements, special tax deduction rates etc. This has been undertaken in for example Japan and Korea. However, this study show that financing CAD investment is probably not an obstacle since the investment can be quite small and capital costs seem not to play a role in the adoption decision.

Finally, there are indications of a proliferation of the sources of innovation due to the licensing of production of specialized and/or customer adapted PC CAD[18]. Furthermore, the technology is developing towards cheaper, easier to install and use, CAD systems. This speaks against costly intervention of any type.

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[17] As shown by Swan (1973) the growth of a domestic industry increase domestic diffusion under international supply restrictions.

[18] Autodesk AB (Sweden) was inaguarated in 1984. In 1989, there were already at least 20 Swedish firms working as third-party developers for Autodesk and four more distributors for the Swedish market (Autodesk AB, 1989).

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The Diffusion of Industrial Robots and CIM in Japan

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1.INTRODUCTION

It is well recognized that computer aided manufacturing systems are the key factors for productivity improvement and technological innovation. From engineering point of view, many researchers have reported the various kinds of the effects of CIM technologies based on case studies and surveys. [Bessant, 1985][Haywood, 1987] [Sheinin, 1987] [Tchijov,1988] However, there are only few investigations concerning with the social and macro economic effects of the computer aided new manufacturing systems. *Technological Forecasting and Social Change* 35 published in 1989, a special issue on this subject, summarized the subject.

In case of Japan, fortunately well established statistics on the shipment of industrial robots are available from *Japan Industrial Robot Association*. Some surveys on the diffusion, possibility and barriers of CIM, CAD/CAM and information technologies are also reported by *Economic Research Institute of Japan Society for the Promotion of Machine Industry* (JSPMI-ERI) and *NIKKEI Computer Graphics*, etc. Based on them, the author reported the macroeconomic effects of industrial robots [Mori, 1989A] and trends and problems of CIM. [Mori, 1989B]

After these two papers are published, the background of the Japanese manufacturing industries has changed in some remarkable points.

1.The shipment of industrial robots went down in 1986 and 1987 because of a small recession caused by higher exchange rate of yen.
2.The price of PC's and engineering work stations (EWS) have rapidly went down and the tendency is still continuing.

These points might affect the diffusion procedure of industrial robots and computer aided manufacturing systems. The purpose of this paper is to revaluate and compare the macro effects of industrial robots and CIM systems with the above papers and then to see the future trends of these systems.

2.DIFFUSION OF INDUSTRIAL ROBOTS

The diffusion process of industrial robot has been discussed by Mori[Mori, 1989A], Tani[Tani, 1989] and Maly [Maly, 1989]. Mori proposed an production function model to evaluate the macro economic effects of industrial robots. Analysing the statistics from 1970 to 1985, he suggested that the economic effects of industrial robots were almost saturated although their shipment were still growing rapidly. In the remainder of this section, the author describes the trend change in Japanese manufacturing industries.

FIGURE.1 and FIGURE.2 exhibit the trends of total number of human workers and value added of Japanese manufacturing industries. The economic growth in 1970's still continues in the 1980's while number of human workers is almost constant in these twenty years. FIGURE.3 shows the shipments of industrial robot in units to whole manufacturing industry and five sectors, i.e. chemical products (denoted by chem.), metal products (denoted by metal.), general machinery industry (denoted by gen.mach), electric machinery industry (denoted by elc.mach.) and transportation machinery (denoted by trn.mch.). In 1986 and 1987, corresponding to the recession shown in FIGURE.2, they went down sharply. FIGURE.4 exhibits the population of industrial robots per 1000 human workers. In chemical products industry, since simple industrial robots (mainly fixed sequential robots) are used for products extractor from mold, it is almost ten times of average value.

These figures may conclude that the diffusion process of industrial robots is still going on. But it should be noted that if they are still continuing to replace human workers and the price of sophisticated robots are going on - it is correct as is shown in FIGURE.6 -, the share of the latter should have been increasing to replace more complex jobs. In this sense, the trend of the share of sophisticated robots, i.e. play back robots, NC robots and intelligent robots which are controlled by computer, may provide a important information.

FIGURE.5 shows the shipment share among industrial robot types in whole manufacturing industry. It is shown that the share of them is still increasing, but their growth is almost flat in these five years. FIGURE.6 is trends of logit transformation of their share, for instance $\ln\{S/(1-S)\}$ for the above five industry sectors and whole manufacturing. We can observe that sophisticated robots rapidly penetrated the manufacturing industry around 1980. It might be suggested that their contribution to the production systems already comes to a stationary level in these years. It may be useful to see the hypothesis, how the equivalent workers per industrial robot which represents the labor substitutability effect and benefit rate of industrial robot capital stock introduced by Mori[1989A] are changing. Let me describe their estimation procedure briefly. Let L and R denote the labor and robot capital stock. Then their total labor force F(L,R) is assumed to be formulated as

$$F(L,R)=(L^{a} + A\cdot R^{a})^{(1/a)}. \tag{1}$$

Given their prices, P_L and P_R, the their optimal input can be derived as

$$A(R/L)^{a-1}=(P_R/P_L). \tag{2}$$

Therefore the parameters A and a can be estimated from historical data. The equivalent labor force E_R and benefit rate B_R are defined as follows:

$$E_R=\{F(L,R)-L\}/U \tag{3}$$

$$B_R=\{P_L F(L,R)-(P_L L+P_R R)\}/R \tag{4}$$

where U denotes industrial robot population.

FIGURE.7 exhibits the trends of average wage and price index of industrial robots. Following to the above (Mori,1989A), Divisia price index is employed. The relative price of industrial robots are still continuously going down. Assuming the annual expense rate to be 35%, which is similar to the high case of the above paper, one can calculate the annual expenditure (capital cost) of industrial robots. FIGURE.8 exhibits its ratio to the total wage.

It may be interesting that these ratios are clearly classified into two groups. Chemical product, electric machinery and transportation machinery industries pay relatively high robot cost which are more than twice of whole manufacturing.

The results on the benefit rate and equivalent workers per robot are shown in FIGURE.9 and FIGURE.10. Since the equivalent workers per robot are almost constant after 1984, it is suggested that the job constitution substituted by industrial robots is quite stable in these years. As is shown in FIGURE.9, their benefit rates are likely to converge around 15% for all industries. These findings are well compatible with the above hypothesis.

After all, it could be concluded that the diffusion process of industrial robots in 1980's is not mainly motivated by technological innovation (excluding robot price reduction) but by the economic reasons. However, it should be emphasized that the above finding does not mean the technological saturation of potential automatization possibility in the firms. Table.1 [JIRA,1989] summarizes the potential automatization rate based on the 1052 sample survey. The values represent the potential automatization rate of the present manual process, not of the whole process. Unfortunately, the present automatization rates in whole process are not available. Table.2 [JSPMI-ERI,1986] shows the actual and future automatization rates assessed in 1986. According to them, one can evaluate the final the final automatization rate to be about 60% - 70% of total process.

Some remarkable points are shown in the latest survey [JIRA, 1989] shown in Table.3 and Table.6.

In Table.3, adapting to the products diversification is pointed out as a very important purpose as well as the capacity utilization improvement and working environment improvement. Coping with less human worker availability is not so important. In Table.6 one can find the "more sophisticated control" and "pattern recognition" to be the future important factor for the industrial robots as well as "cheaper price". The above two tables suggest that the contribution of industrial robots may come to the next stage in the near future.

3.DIFFUSION AND PROBLEMS OF CIM

Many researchers have discussed the driving force of CIM technologies other than direct cost reduction. For instance, Ayres [Ayres,1987] pointed out the five categories of CIM benefits. Namely, (1).labor force reduction, (2).capacity augmenting, (3).capital sharing, (4).product quality improvement and (5).acceleration of product performance innovation.

The author summarized the existing surveys on CIM diffusion process and its problems. [Mori, 1989B] In 1989, two new survey results are additionally available. The one is given by JSPMI-ERI entitled "Concept of Market-oriented CIM and Company Structure Integration" and the one done by the author and K.Maruyama. Market-oriented CIM is defined as a integrated computer aided manufacturing system directly connected with the marketing information. Traditional Japanese factories did not strictly distinguish CIM from FA and its variation. Therefore it is a concept of "true CIM".

Although the latter consists of only 8 answers and 4 interviews, some interesting comments have been collected. The sample number of the former is unknown.

In the remainder of this paper, the author describes some findings and trend change briefly.

FIGURE.11 compares the main purpose of CIM by survey year. (1989 survey is given by the author.) Although the coverage of each survey is much different, one can see the importance of the reduction of direct cost is increasing. Adaptation to the design change is not so high. On the other hand, Table.4 [JSPMI-ERI,1989] points out the high score of communication and adaptability to market change as a purpose of market-oriented CIM. The cost reduction effect is important in the long range. These are different from FIGURE.11 and TABLE.5 [JSPMI-ERI,1985]. The reason may come from the definition of CIM, involving market information feedback system or not. Investment for marketing information system aims at future possible effects. Then the question is how the integration really provides outcomes. FIGURE.12 is extracted from the case study of CIM.[JSPMI-ERI,1989] This company started to integrate total systems by computer in 1978. Both total sales per worker have grown up parallel to products turnover.

Table.7 shows the outcome of the market-oriented CIM in machinery industry. [JSPMI-ERI,1989] It is observed that more than 60% firms are satisfied in most of the items, except for quality improvement and material cost reduction, which have been regarded as a main purpose of traditional FA and industrial robots. It should be noted that the "very good" and "good" outcome of market-oriented CIM are in terms of better customer services. Taking into account the findings in the TABLE.3 in the previous section and surveys before 1987 by JSPMI-ERI, the purpose of CIM integration is moving from production improvement to marketing adaptation.

Table.9 exhibits the barrier of market oriented CIM. [JSPMI-ERI, 1989] Here the most serious problem is not cost related items but "lack of system engineer". The second serious problem is "software". These points are also pointed out by the interviewed managers. These may also suggest the changing situation of CIM.

TABLE.8 and FIGURE.13 exhibit the comparison between before and after CIM implementation given by the author's interviews. Here cost reduction effects are also relatively low. It may be noteworthy that the patterns of CIM effects are quite similar, as is shown in FIGURE.13, although only three answers are available.

Through the interviews, some remarkable comments are collected:
"Some hardware problems occurred to the connection with the information network because there are too many kinds work stations."
"No existing software is available for our system. But we have too few system engineers to build it up by ourselves."
"The new management system crossing over the divisions is needed to construct CIM."
"We do not think the ultimate factory to be unmanned huge system. Flexibility of human workers should be involved."
All the interviewed managers were more or less negative to the MAP systems.

4.CONCLUSION

This paper has dealt with the recent statistics on industrial robots and CIM surveys. As is discussed in the section 2, the role of industrial robots is likely stable and they are implemented because of economic reasons rather than technological progress in these years. However, some figures suggest that its situation is changing.

The above tendency is also seen in case of FA and CIM. "Integration" now seems to arrive at the new stage involving market information feedbacks. Needless to say, it was the origin of CIM. But when we remember that many of Japanese FA and CIM systems have been constructed through the "bottom up" approach [JSPMI-ERI,1987], it may suggest that the CIM is diffusing from production division to the new business arena.

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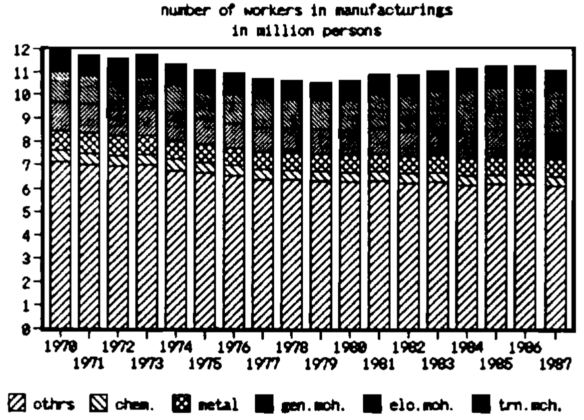

FIGURE.1 Number of human workers in manufactuing industry

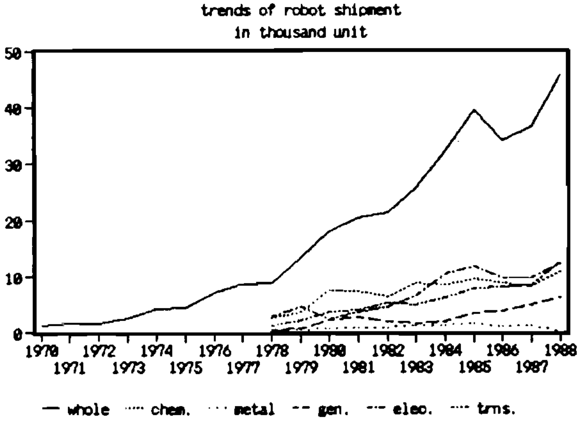

FIGURE.3 Trends of industrial robot shipment by industry

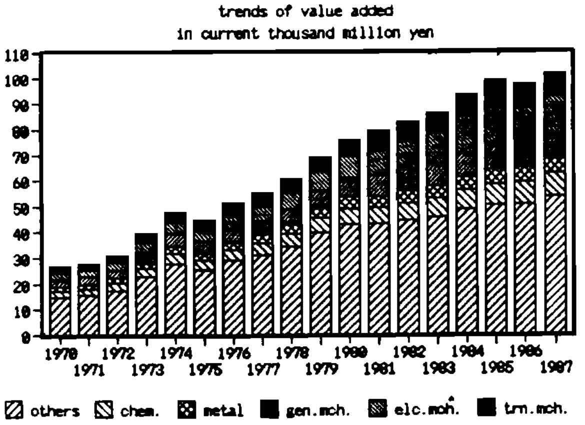

FIGURE.2 Trends of value added of manufacturing industries

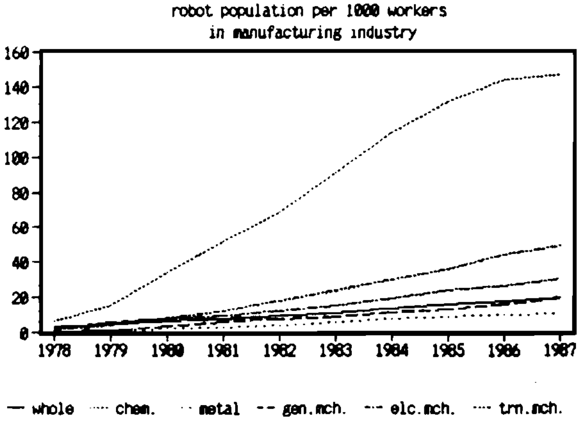

FIGURE.4 Industrial robot population by industry

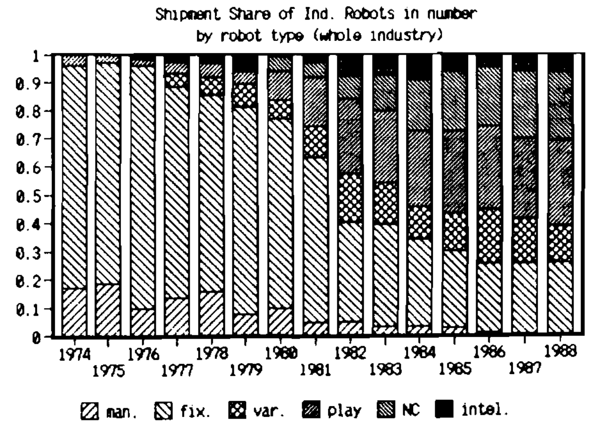

FIGURE.5 Shipment share of industrial robots by robot type

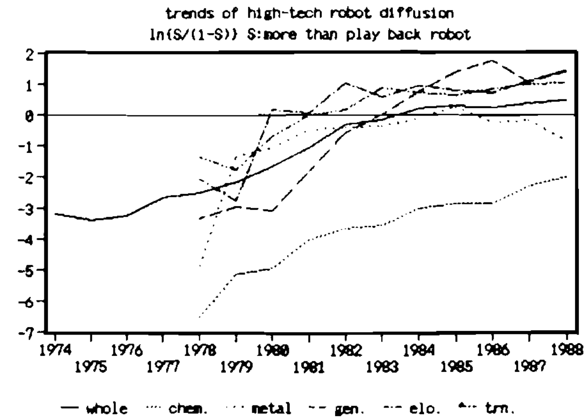

FIGURE.6 Trends of computer controlled robot share

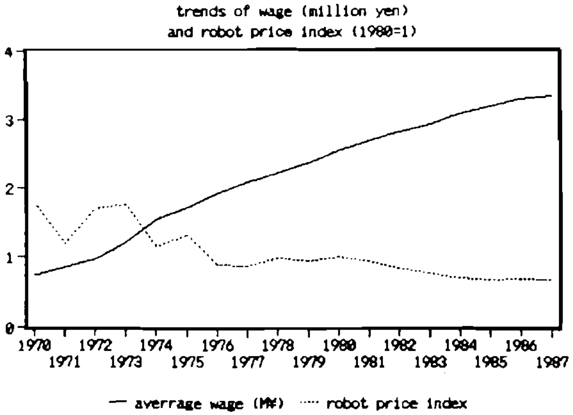

FIGURE.7 Trends of wage and industrial robot price index

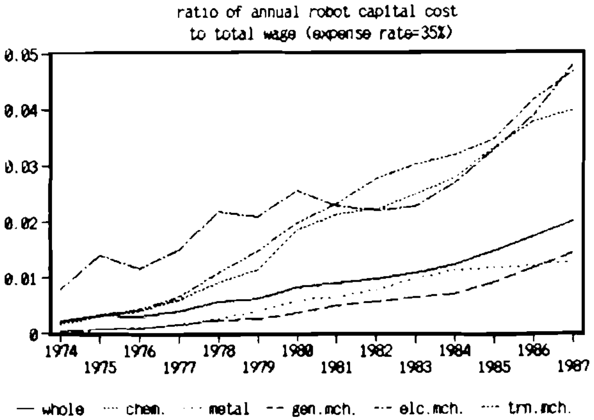

FIGURE.8 Ratio of annual robot capital cost to total wage

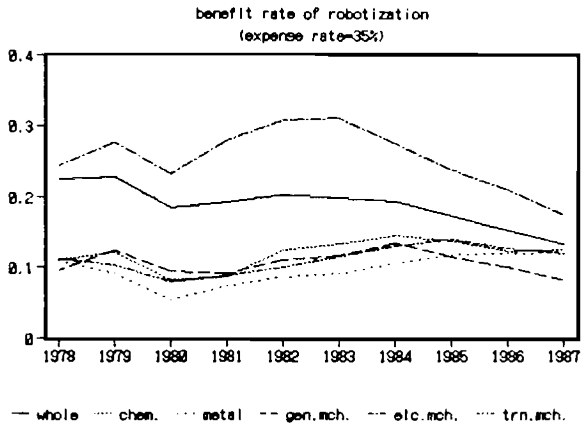

FIGURE.9 Trends of benefit rate of robotization

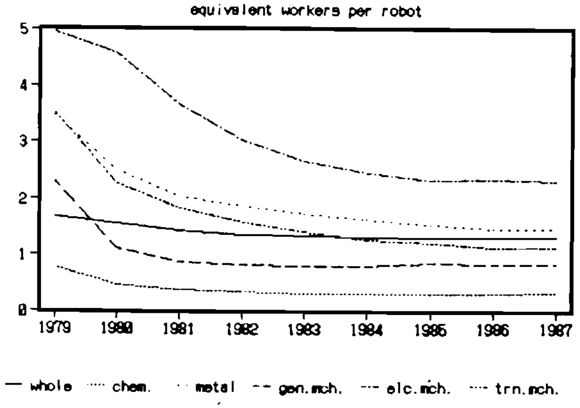

FIGURE.10 Trends of equivalent workers per industrial robot

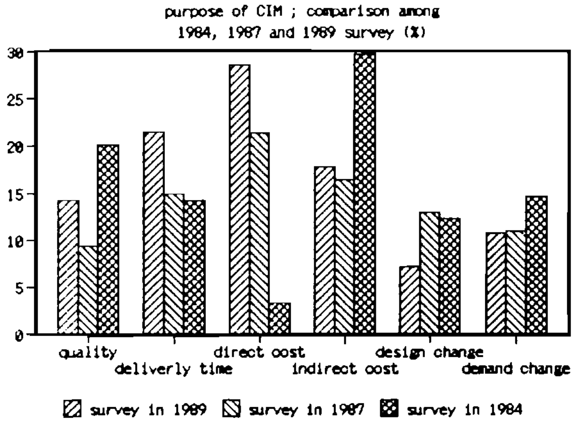

FIGURE.11 Purpose of CIM ; comparison among surveys in 1984,1987 and 1989

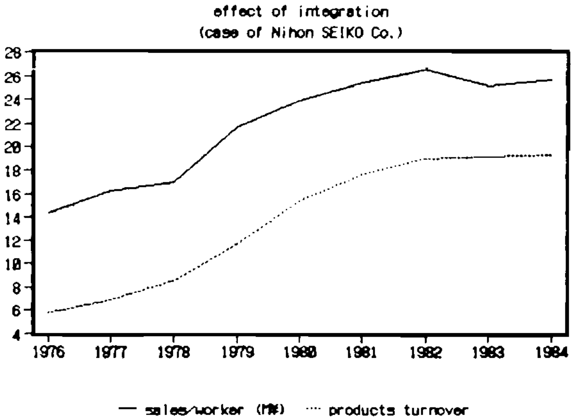

FIGURE.12 Example of CIM integration effect ; case study

Table. 1 potential automatization rate ; by job type and industry sector (%)

industry sector	casting	die-casting	plastic forming	heat treatment	forging	press & shearing	arc welding	spot welding	gas welding	painting	plating & surfacing	grinding	assembly light-1	assembly light-2	assembly mid &hvy	loading	inspection	others	average
food										30	40	10	30	30	37.5	33.9	43.3	37.6	35.9
textile																26.7	46.7	45.8	42.8
wood & wood products			30							15		20			20	55	10	30	28
pulp and paper			30											30		15		38	31.1
chemical products			44			60				30	40	80	80	42.5	45	44.3	50.9	45.6	47.5
oil & coal products			55									20		80		45	55	48.6	50
rubber products			20			50				15		10	50	30	50	50	40	38.8	34.2
cement and cray			30			26.7	40	40	30	60	70	35		60	70	27.5	36.7	41	39.7
iron & steel	25			45	33.3	60	10			20	30	45		60	50	43.3	41.1	50	40
non-ferrous metals	28.8	40	45		40	35	15	20	10	50	40	35.5	45	40	40	35	27.1	33.3	35.1
metal products	24.3	30	10	31.7	35	33.8	40.8	41.1	5	51.3	40	45.7	55	36.2	33.3	42.5	40	56.7	40.3
general machinery	34	51.7	40	17	40	24.3	28.8	37.1	46.7	46.4	16.7	37	24.3	40	29	25.7	22.7	35	33.5
electrric machinery	25	45	43.2	57.5	50	40.5	32.1	43.9	27.5	44.5	35	36.9	48.3	39.2	33.4	38.9	42.7	49.2	40.9
automobile	28.6	37.5	33.5	37.1	55	48	48.3	46.8	10	44.1	20	45	46	35.9	28	13.3	25.6	30	40
other transportation	23.3	20	50	32.5	30	44	35.9	45		46.2		42.7	10	37.1	23.3	40	40	33.3	37.9
precision machinery	40		45	50		20	40	20	100	39.1		38.8	37.9	35.4	30	28.8	44.3	40	38.3
plastic products			38.1							40	10	45	20	40		42	30	40	37.6
others	50		30	20	75	25	45.7	35		48.6	30	35	45.7	50	55	36.3	43.3	33.7	39.9
total	29.5	40.3	38.7	32.6	43.8	37	37.4	42.5	30.6	44.6	33.1	39.6	44.9	39.4	34	36.7	39.1	41.3	39.2

source:JIRA(1989)

Table.2 Automatization Rate 1983,1985 and 1988
by Job Type

	year	TOTAL 186	General machinery 65	Electric machinery 48	Transport. machinery 57	Precision machinery 16
1.design & drafting	1982	18.1	23.1	11.2	21.3	12.5
	1985	27	26.9	23.3	29.4	32.2
	1988	46.2	44.7	41.5	47.9	58.3
2.metal molding	1982	29.5	46.5	20.5	27.1	23.3
	1985	32.9	46.5	26.4	30.3	34.2
	1988	56.1	57.3	39.3	45.2	45.8
3.press	1982	37.3	40.1	37.3	32.7	50
	1985	47.4	48.7	47.6	41.9	61.7
	1988	57.2	60.9	58.3	51.8	70.8
4.plastic forming	1982	40.4	49.4	40	29	48
	1985	51.3	60	53.1	42.6	56.7
	1988	60.7	71.7	60.4	56.8	56
5.machining	1982	33.3	38.3	27.1	27.4	38.5
	1985	54.5	46.1	39.7	39.5	57.3
	1988	55.8	57.6	49.6	54.3	65.8
6.assembly (machinery)	1982	23.4	25.1	23.7	21.3	20
	1985	29.4	28	29	30.5	33.8
	1988	37.2	34.4	36.6	38.8	45.6
7.assembly (electric)	1982	23.2	23.1	23	21	25.7
	1985	32.6	31.6	31.8	31.4	36.8
	1988	46.4	38.8	44.7	50.9	58.4
8.welding	1982	32.7	33.6	37.9	34.5	46.7
	1985	39.6	34.8	37.8	44.3	42
	1988	51.3	44.2	48.2	58.3	58
9.painting	1982	42.2	41.1	53.6	38.6	42
	1985	48.7	48.1	47.2	49.6	50.7
	1988	55.2	52.6	51.2	57.9	62.1
10.total system	1982	25.5	23.6	27.3	26.8	24.1
	1985	35.3	34.3	37.7	33.3	39.1
	1988	48.4	43.5	52.1	48.6	57.7

Source:Progress of FA and Structual Change
in Subccontract Companies (JSPMI-ERI,1986)

Table.3 incentive for industrial robot implementation ; by industry sector

industry sector	divesification of products	flexibility of process line	capacity utili-zation rate up	quality & yield rate up	better finance circumstance	working env. improvent	less available workes	more safety in factory	young workers less available	skilled workers less available	energy & re-source saving	others
food	A				B	C						
textile	A		B			C			C			
wood & wood products					B	B				A		
pulp and paper	A		C		B							
chemical products	B				C	A						
oil & coal products					B	A		C				
rubber products	A		A	A		A						
cement and clay	A				B	B						
iron & steel			B			A		C				
non-ferrous metals	A		A			A						
metal products			B		B	A						
general machinery			A		B	C						
electrric machinery	A	B	C									
automobile	A	B	C									
other transportation	C		A			B				C		
precision machinery	B		A		C							
plastic products			A	C	A							
others	A		C		B							

A:very source:JIRA(1989)
B:important
C:rather important

Table.4 purpose of market-oriented CIM in machinery industry (%)

	short term(2-3 years) very good	good	no effect	nega-tive	long term(5 years) very good	good	no effect	nega-tive
effective communication	21.4	61.9	14.3	2.4	51.2	42.9	3.6	2.4
adaptability to market change	23.5	49.4	24.7	2.4	47.1	41.2	9.4	2.4
development force improvement	12.2	51.2	35.4	1.2	31	51.2	16.7	1.2
cost reduction	9.4	54.1	30.6	5.9	32.9	52.9	8.2	5.9
feedstock reduction	15.3	60	21.2	3.6	43.5	45.9	7.1	3.6
product stock reduction	15.3	50.6	32.9	1.2	38.8	42.4	17.6	1.2
marketing support	3.7	47.6	48.8	0	20.2	53.6	25	1.2
business extension	2.5	38.3	58	1.2	19.3	38.6	41	1.2
restructuring	10	40	48.8	1.3	22	56.1	20.7	1.2
improvement of total power	12	59	26.5	2.4	31.8	51.8	14.1	2.4

source:Concept of Market-oriented CIM and Company Structure Integration (JSPMI-ERI,1989)

Table.5 Main Purpose of FA in 213 factories

(%)	TOTAL	General machinery	Electric machinery	Transport. machinery	Precision machinery
quality of products	54.5	45.0	64.1	65.1	37.5
lead time reduction	38.5	46.3	40.6	23.3	37.5
human saving	80.3	83.8	81.3	81.4	62.5
production capacity	39.4	45.0	48.4	14.0	62.5
flexibility	33.3	41.3	23.4	37.2	31.3
cost stablilization	8.9	11.3	3.1	9.3	12.5
safety of workers	12.7	7.5	7.8	30.2	.0
others	2.8	3.8	3.1	.0	.0

Source:Advances of FA and Future Issues (JSPMI-ERI 1985)

Table.6 future problems of industrial robot penetration by industry sector

	speed	precision	degree of freedom	sophisticated control	weight of robot	heavy load handling	pattern recognition	size	reliability	cleanness	price
food	○			○			○				◎
textile				○			◎			○	
wood & wood products											◎
pulp and paper	○		○			○	○		○		○
chemical products				◎			◎				◎
oil & coal products	◎			○			○		○		○
rubber products							○		◎		○
cement and clay		○		○			○		○		○
iron & steel	○	○		○		○	○				◎
non-ferrous metals				◎			○				◎
metal products		○		○			○		○		◎
general machinery		○		○		○	◎				◎
electrric machinery				○			◎				◎
automobile	○	○		○							◎
other transportation				○			○				◎
precision machinery	○			○			○				◎
plastic products				○			○				◎
others	○						◎		○		◎

◎:very source:JIRA(1989)
○:important

Table.7 outcome of market-oriented CIM in machinery industry (%)

	very good	good	no effect	negative
better customer servive	19.1	60.7	20.2	0
market information feedback	10.1	43.8	44.9	1.1
effective business	13.8	65.5	20.7	0
design time reduction	19.3	51.1	26.1	3.4
standardization	20.2	43.8	33.7	2.2
production time reduction	22.5	56.2	21.3	0
quality improvement	9	43.8	47.2	0
material cost reduction	1.1	40.9	55.7	2.3
effective office work	36.3	51.6	11	1.1
sales/benefit growth	7.9	57.3	34.8	0

source:Concept of Market-oriented CIM and Company Structure Integration (JSPMI-ERI,1989)

Table.9 barrier against market-oriented CIM construction (%)

	very serious	serious	not serious
huge investment	36.7	49.4	13.9
large operating cost	24.1	55.7	20.3
lack of engineer	51.9	42.0	6.2
software	45.0	45.0	10.0
lack of standardization	39.7	41.0	19.2
hardware	13.2	40.8	46.1
lack of flexibility	28.2	51.3	20.5
lack of database	28.2	52.6	19.2
lack of network system	28.8	48.8	22.5
protcol problem	24.0	48.0	28.0
cost comparison with human	6.3	36.7	57.0
back up of top management	16.5	39.2	44.3
maching with QC circles	3.8	30.0	66.3

source:Concept of Market-oriented CIM and Company Structure Integration (JSPMI-ERI,1989)

Table.8 Outcome of CIM ; comparison before and after CIM

		before	after			
			R Co.	Y Co.	K Co.	average
labor saving in	design division	100	90	60		75.0
	production division	100	50	70	80	66.7
	management division	100	50	50		50.0
cost reduction in	inventory	100	80	50	70	66.7
	material	100	70	90		80.0
	operation	100	80	80	80	80.0
lead time reduction in	design	100	50	60		55.0
	production	100	70	60	70	66.7
	shipment	100	80	60	70	70.0

source: Mori & Maruyama in 1989

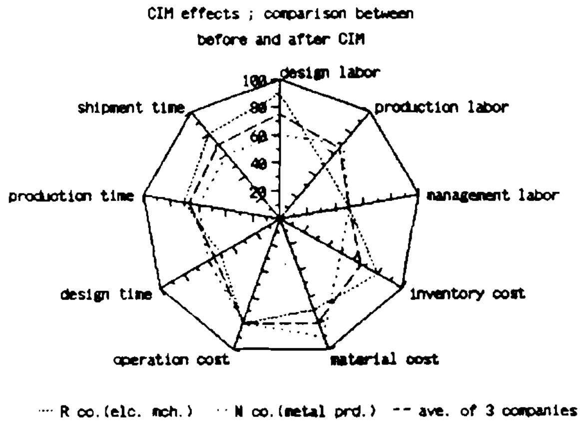

FIGURE.13 Cim effects; comparison between before and after CIM

The Diffusion of Flexible Manufacturing Systems (FMS)

by

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Computer integrated manufacturing (CIM) has yet to be defined clearly, but specialists recognize, that FMS is a key element of the CIM concept. FMS plays the main role in the production process, fulfilling metalcutting, metalforming, joining, assembly and often quality control operations.

The FMS efficiency, or its economic profitability crucially depends on the use of these supplementary elements (the 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), in 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.

These aspects will be analyzed in this chapter, and in the context of an FMS diffusion study based on the World FMS Data Bank developed in IIASA's CIM Project.

FMS Driving Forces

At its first stage, the goal of industrial development 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 – assembly, quality control, tuning, etc. – were the privilege of more highly-skilled workers. 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.

In the second part of this century when 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. Differentiation of goods production due to their quality and other specific features grew.

The shorter life cycle of goods demands a higher cost of production line reequipping. This is true for standalone 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. The introduction of FMS may help in reducing the cost of model change and make the problem of product innovation easier. Currently, 60–70% of all metalworking industries output in developed countries are of a small batch size, thus, a shift from "economy of scale" to "economy of scope" become unavoidable.

Thus, one of the factors, which caused a rejection of the concept of mass production, has been *demand changes.* At the same time, within production itself, new factors came into being, and brought to life a new style of industrial production. One of the technological ones – cost growth due to the increasing needs for intermediate control when parts production is spread over space and time.

The process of quality improvement as well as the creation of products satisfying new customer needs includes a fundamental internal conflict when the design engineer would like to achieve a functional superiority with higher product complexity, but the production engineer wants to simplify components and product assembly. FMS facilitate smoothing these contradictions through so-called "redesign processes". Higher demands on product quality and technological sophistication, which require the precise following of technological norms, as well as the necessity to reduce the control processes and inventory costs, are leading to the substitution of computer control in place of 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

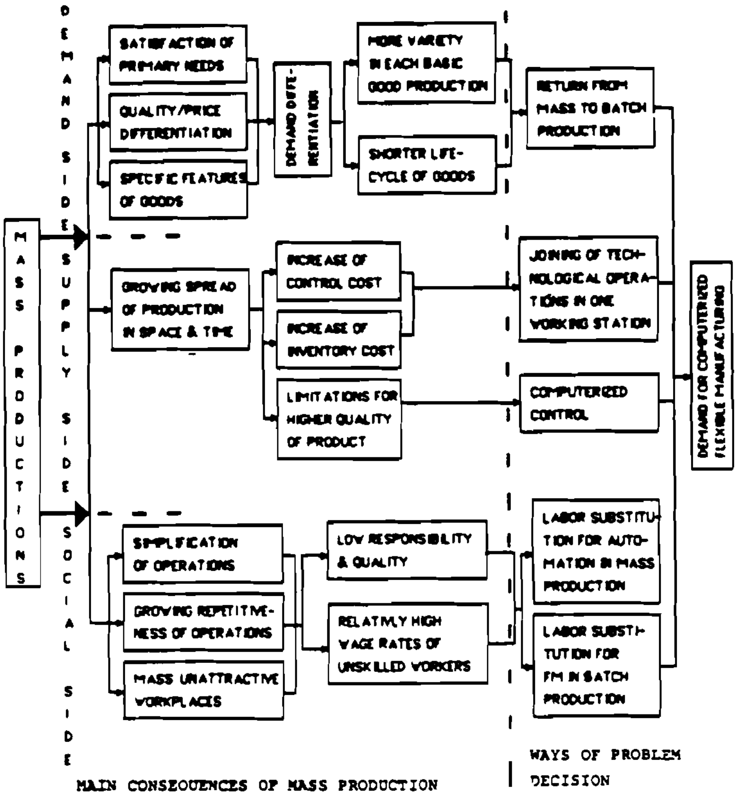

Figure 1. Driving forces of computer integrated flexible manufacturing.

socio-psychological sphere. The tendency to the division of labor, simplification of operations performed by a worker and the introduction of conveyor driven mass production systems determined the pace of operations, led to a growth in the share of unskilled workers performing simplified operations repeatedly and monotonously.

It is quite obvious that in industrial production physiologically non-attractive and socially non-prestigious types of activity became endemic. A dichotomy came into view when unskilled (but unattractive) labor became similarly paid (sometimes, even higher), as complicated and skilled ones.

As an attempt to overcome these contradictions, in some cases human labor in monotonously repetitive and unattractive operations was substituted for by automated tools. This took place first in mass or 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 fulfill this role. The replacement of man by computerized equipment, encounters a number of social difficulties. Major amongst these is connected with the risk to become jobless, inertia of thinking, habits and behavioral stereotypes. The skill demands to operate new technologies are very high, the personal responsibility increases due to the extremely high cost of human errors. According to Japanese data 60% of all FMS failures take place due to operators' errors, 25% – to engineers' errors and only 15% because of tools problems.

The interrelations of the driving forces, generated in the process of substitution of mass production by the flexible processes are shown in *Figure 1.*

Table 1. Number of cases with the main FMS indicators.

Indicators	Ver.4	Share in total, %
1. Technical complexity (TC), index	784	89
2. Number of product variants (PV), units	525	60
3. Average batch size (BS), units	259	29
4. Investment cost (INV), US$ mill.	314	36
5. Pay-back time (PBT), years	98	11
Reduction of, by a factor of		
6. Lead time (LTR)	107	12
7. Set-up time (SUT)	45	5
8. In-process time (IPT)	90	10
9. Machining time (MT)	46	5
10. Inventories (INR)	53	6
11. Work-in-progress (WIP)	80	9
12. Personnel (PER)	187	21
13. Number of machine tools (NOM)	94	11
14. Unit cost (UCR)	58	8
Increase of, by a factor of		
15. Productivity (PRO)	88	10
16. Capacity utilization (CAP)	84	10
Total	880	-

World FMS Data Bank

To analyze the state of the art, the competitive positions and the future expansion of these sophisticated technological systems, we needed several sets of data as a minimum. The first set was to describe the costs of FMS and the pay-back time. The second one was to represent different economic advantages of the systems (labor and capital saving, etc.). The third one had to reflect operational modes and technical features of the object. Finally, to avoid duplication, we had to identify different systems by industries and areas of their application, types of production, etc. Here the study, based on the fourth bank version, will be described.

The bank now contains 33 indicators describing about 900 FMS installed in 29 countries. Not all the cases include the full set of the variables, but the amount of data for each variable is highly representative in the fourth version of the bank (see *Table 1*).

There are also four indicators serving for FMS identification. They include country names (COUN), names of company users including their allocation (COMP), names of main vendors of the systems (VEN) and years of installation (YEAR). Another group of indicators describes the technical complexity of FMS and includes: the number of machining centers (MC), the number of other NC-machines (NC), the total number of NC-machines (NCMT), the number of industrial robots (ROB), types of transportation (TRT), storage (STOR) and inspection (INSP) systems as well as a synthetic indicator of technical complexity (TC). The weighted formula to calculate it is as follows:

$$\mathrm{TC} = 0.35\mathrm{NC} + 0.7\mathrm{MC} + 0.3\mathrm{ROB} + 0.3\mathrm{TRT}$$

There are three types of data in the "Economic and operational data" section; investments and pay-back time (INV, PBT), total number of shifts and number of unmanned shifts a day (OPR, UNM), number of products and average batch size (flexibility indicators) (PV, BS).

The relative advantages of FMS in comparison with previous modes of production (conventional machines, stand-alone NC-machines, or FMC) were measured in terms of unit cost reduction (UCR), or labor saving (PER, PROD), fixed capital elements saving (FLS, NOM, CAP), current expenditures saving (INR, WIP), time saving (LTR, SUT, IPT, MT).

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. CSSR	23	2.6
6. Finland	12	1.4
7. France	72	8.2
8. FRG	85	9.7
9. GDR	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. South Korea	4	0.5
22. Spain	2	0.2
23. Sweden	37	4.2
24. Switzerland	6	0.7
25. Taiwan	5	0.6
26. UK	97	11.0
27. USA	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

FMS Diffusion

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 real diffusion, which is due to a difference of availability of information from the respective countries.

It is obvious from the table that there are two leaders among the countries – Japan and the USA (24% and 16% of the total FMS population, respectively). The second group includes those countries with a share from 5 to 11% - France, the FRG, the UK and the USSR. The CSSR, the GDR, Italy and Sweden own possess between 2.5% and 5% each of the total FMS population. 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.

As is shown in *Figure 2*, 80% of the systems 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 5 years old.

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 tools building, and the third

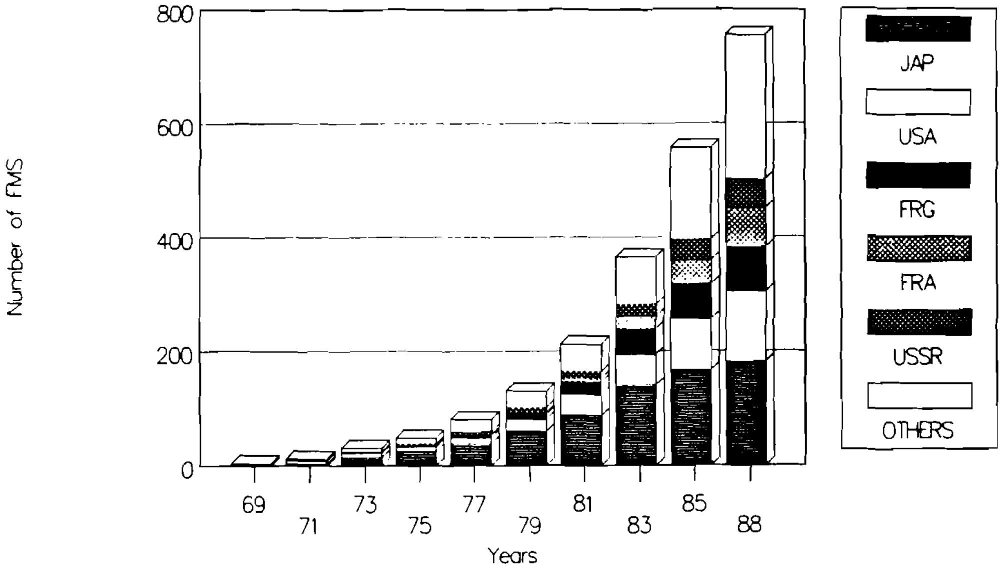

Figure 2. FMS population by the end of a year in the world.

main user sector is electrical machinery. The smallest user among the metalworking industries is instrument production. According to technological processes similarity the industries were aggregated into two industrial sectors shown in the bank:

1. transportation equipment, non-electrical machinery, large electrical machines;
2. electronics and instruments.

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. But the process of the real FMS diffusion, when the annual number of installations exceeded five, only began in 1982–83.

With regard to technological areas in FMS application (APP) 76% of systems 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 and combining machining and assembly processes appeared much later than pure machining FMS, but the growth rate of the former was higher. It means that the future growth of FMS technologies will be based also on a rapid growth of new niches (assembly and manufacturing), and especially in electronics and instruments.

"Portrait" of a Typical FMS

In reality, the total FMS population is a "mixed salad" including systems of different technical complexity, producing different types of parts by different modes. They have different economic

Table 3. The average FMS characteristics by areas of application.

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

***Number of observations is not enough for averaging

advantages (lower cost, higher flexibility etc.). The figures given in *Table 3* demonstrate examples of FMS used in different areas of application.

One can observe that metal-forming FMS (APP3) have a lower average number of NC-machines, 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) contain both, 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 with very high lead time reductions.

In order to present a "portrait" of a typical FMS we had to cluster the data bank, selecting the most wide spread type – machining systems and manufacturing ones – where metal-cutting processes dominate. Below we shall call them simply "machining FMS". This set includes 731 examples, 64% of which machine prismatic parts, 24% – rotational ones, and 12% – both types of parts.

A simple averaging usually shows significantly shifted figures, while a distribution analysis could provide typical values of the indicators. *Figure 3* reveals, that a typical machining FMS has a technical complexity index equal to around 3, less than the average value shown in *Table 3*.

FMS distribution over the number of NCMT, MC and ROB, demonstrates that 45% of all machining FMS includes 2-4 NCMT, but only 10% of all the cases could be treated as the simplest systems, as they were based on 2-4 machines with one function. The others included machining centers. Systems with medium complexity in terms of NC-machine number (from 5 to 10) have a 40% share, and only 15% of the systems include more than 10 NC-machines. Usually systems with a high number of NC-machines do not include machining centers, for what could be explained by software problems. Less than one quarter of the FMS population is based on NC-machines with one function (usually NC-turning, milling or drilling machines), more than 40% are based on the use of multi-functional machining centers and 35% have mixed architectures.

Approximately 60% out of the 535 machining FMS include 2-4 MC, though 7% of the systems have more than 10 centers. 13% of the FMS, based on MC, include 2 machining centers with no more NC-machines. Naturally, they should be considered as the simplest form of FMS. There were only 179 machining FMS where the use of robots was reported. These are usually used for

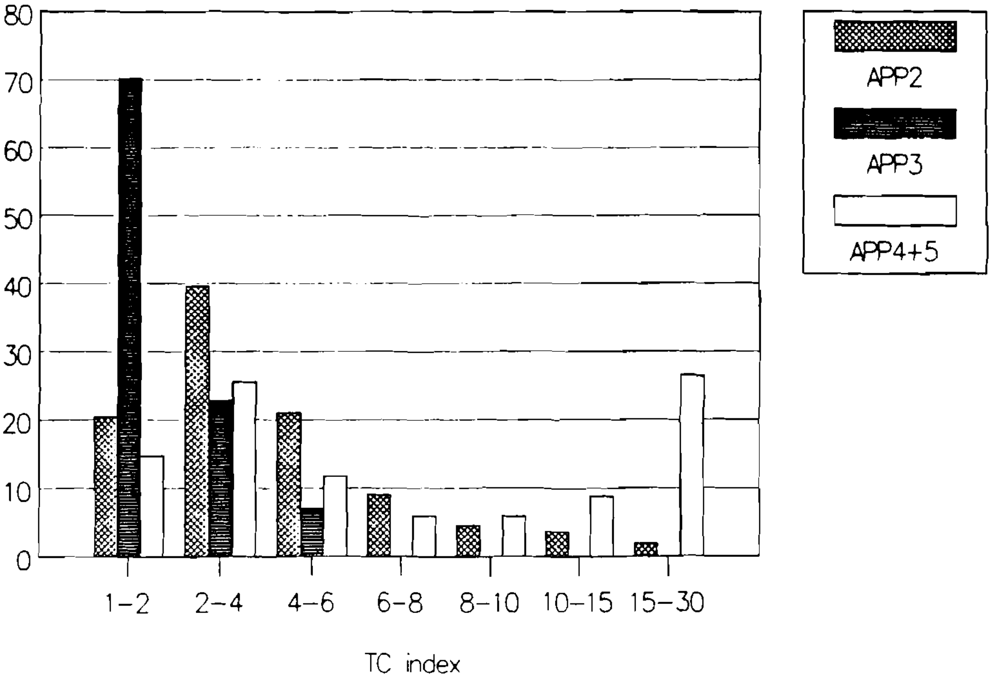

Figure 3. FMS distribution (%) over technical complexity by areas of application.

servicing processes. About 40% of the systems use one robot per system. Robots, however, are the main component of welding and assembly FMS, which on average include 29 robots, with some systems using more than 50 robots.

56% of the 630 FMS, for which the TRT data was reported, use conventional and not truly flexible types of transportation systems (conveyors, cranes, etc.), and 44% use automated guided vehicles and robots. The clustering of storage and inspection systems is rather conditional, and it was difficult to divide the real systems into two classes. This is why we just note that 70% of the 305 machining FMS have conventional storage systems, and 58% of 359 FMS also have conventional inspection systems. Moreover there is a suspicion that in a majority of the cases, where there was no information on the supporting systems, relatively simple ones were used.

The analysis of data from the bank shows that FMS distribution divided by cost is similar to the FMS distribution over technical complexity. More than half of all FMS, where investments were reported, cost less than 3 million US $. Approximately one quarter cost 3-7 mill.$ and one quarter - more than 7 mill. US$. One can also see two rather large families of low-cost (13% of the total, cost 1 mill.$ and less), and expensive (15% of the total, cost more than 10 mill. each) FMS. US FMS dominate among the latter, though among super-expensive systems (five of these where INV>25 mill.$) there are three Japanese systems. FMS distribution over pay-back time is close to normal, with the peak around 3 years. The share of "super-profitable" systems with PBT equal 2 years and less is about 15%. Japan, the UK and Finland each have 3 such FMS. On the other hand, there are 12 FMS (or 16%) with a pay-back time greater than 6 years. Among these there are 9 Czechoslovak systems.

The most typical operational mode of FMS is as follows: 3 shifts a day, including 1 unmanned night shift. Two thirds out of the 276 machining FMS, for whom the information was available, are used during 3 shifts a day, 30% between 1 and 3 shifts and only 9 FMS are used for only 1 shift a day. 72% of 131 FMS are autonomous enough to be used during 1 shift in an unmanned mode, 21% are used automatically for less than one shift, and 5% - longer than 2 shifts.

FMS flexibility is usually measured by two indicators: average batch size and number of

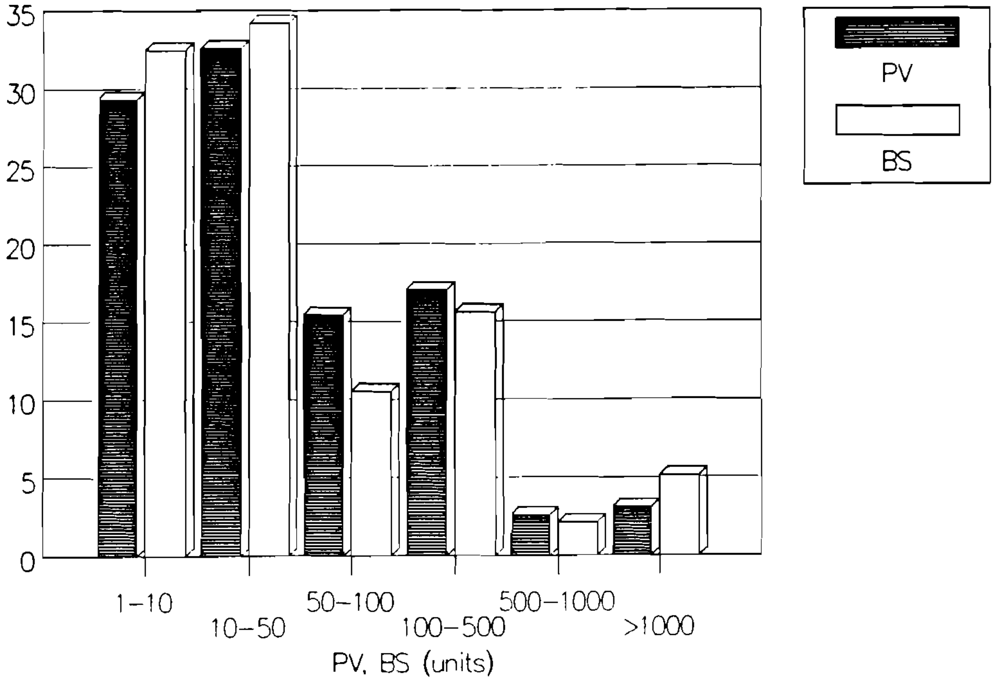

Figure 4. FMS distribution (%) over number of product variants (PV) and average batch size (BS).

product variants. The distribution of the batch sizes, displayed in *Figure 4*, shows that the majority of FMS are really used for small batch production. One third of the FMS produce parts by batches, of 10 or less units a batch, another third by batches of 11 to 50 units a batch. However, 12 FMS (or 5%) are used for large batch production, producing more than 1000 units a batch.

Another indicator of flexibility – the number of product variants (see *Figure 4*) – reveals a rather moderate flexibility of 30% of the FMS. They produce no more than 10 different parts. About 48% of the systems produce from 11 to 100 parts, and the "super-flexible" FMS (3% of the total) are used for the production of more than 1000 parts.

Among 225 cases, where both indicators were reported, one can find three types of production mode. The first one includes FMS producing a very small number of products by small batch size, the second one is characterized by moderate values of both indicators, or big PV with small BS or vice versa. The third type produces a wide variety of products in large batches. These three types could be measured by a product of the indicators – PV*BS. The FMS distribution over the product demonstrates that 60% of the systems belong to the second type (100 < PV*BS < 5000).

The FMS advantages measured in relative terms by increases or decreases in comparison with substituted conventional technologies reflect different aspects of fixed capital, current expenditures and labor saving. Higher flexibility, described in terms of lead time or set-up time reduction could also be expressed in the three categories. 36% of the FMS displayed a moderate lead time reduction by a factor of 1–2 (see *Figure 5*). in comparison with 5.1 on average (see *Table 3*) due to 21 FMS, where the reduction was by factors of between 5 and 10, and 9 systems with LTR greater than 10. The second peak with the high lead time reduction covers systems installed for the sake of greater flexibility and more rapid reaction on demand changes.

There are similar distributions for set-up time and in-process time reductions, see *Figure 5*. One can observe the same two peaks in distribution. One third of 44 FMS revealed set-up

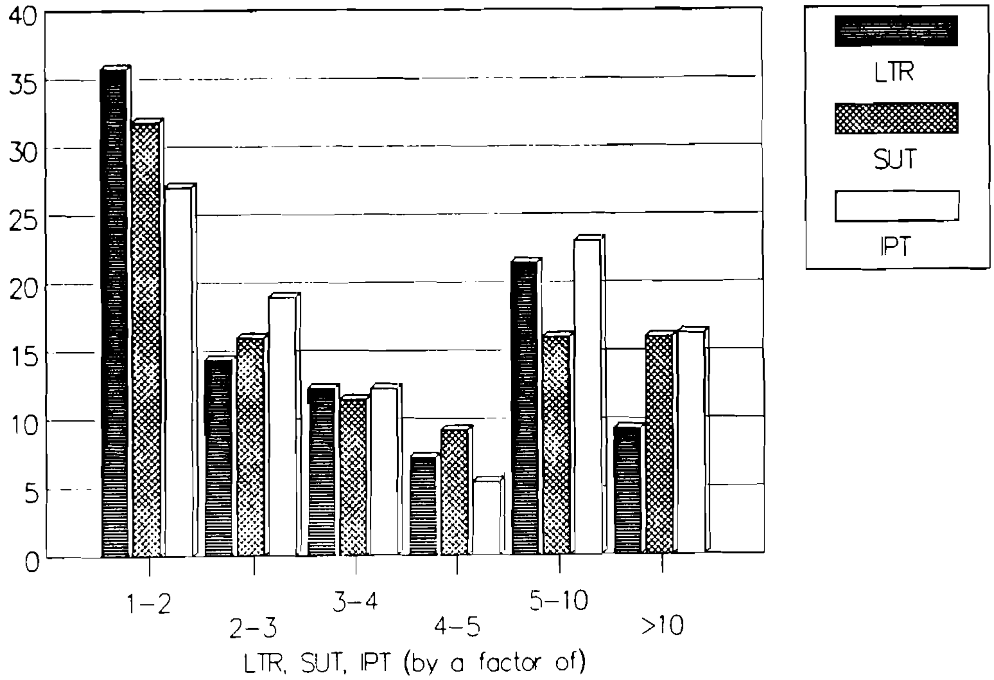

Figure 5. FMS distribution (%) over lead (LTR), set-up (SUT) and in-process (IPT) time reductions.

time reductions by factors of between 1–2, and another third of the systems reduced set-up time almost to zero. 27% of 74 FMS show IPT = 1–2, as well as 23% by 5 to 10 and 16% achieving even higher levels. Machining time reductions per part are more moderate: 72% of 43 FMS had an MT reduction by a factor of 1–2.

The logistic advantages of FMS could be represented by the reduction of raw materials and final goods inventories, as well as by a relative decrease of the work-in-progress (WIP). About half of the FMS display a rather moderate decrease of INR and WIP, no more than by a factor of 2. Among the systems there are 3 FMS which provided practically zero inventories and the other 3 FMS provided almost zero work-in-progress. The exclusion of these somewhat unusual systems decreases the average INR from 3.9 (see *Table 3*) to 2.9 and the average WIP from 3.7 to 3.0.

About 60% of FMS showed a personnel reduction up to a factor of 3, the share of the FMS with a corresponding productivity increase was 64%. The share of "super labor-saver" FMS, which reduced personnel by a factor of 5 and more, was considerably higher too (19%). It means that the latter group of FMS was installed to save relatively expensive labor force or to compensate for its shortage. There are 22 US and Japanese FMS among 30 systems in this group.

The major source of fixed capital saving is the lower number of machines used due to the multi-functionalism of machining centers, the more efficient use of numerically controlled machines. The FMS distribution over The highest share (28%) belongs to those FMS, whose usage led to an NOM reduction by a factor of 2–3. More than one fifth of the FMS have 5 times fewer machine tools than their conventional predecessors. This saving could compensate the higher cost of NC-machine tools, which are 3–3.5 times more expensive than corresponding non-NC machines.

The capacity utilization rate, measured as the share of machining time in total disposable time, increased by a factor of 1.8 on average. For the majority of the FMS where the CAP was

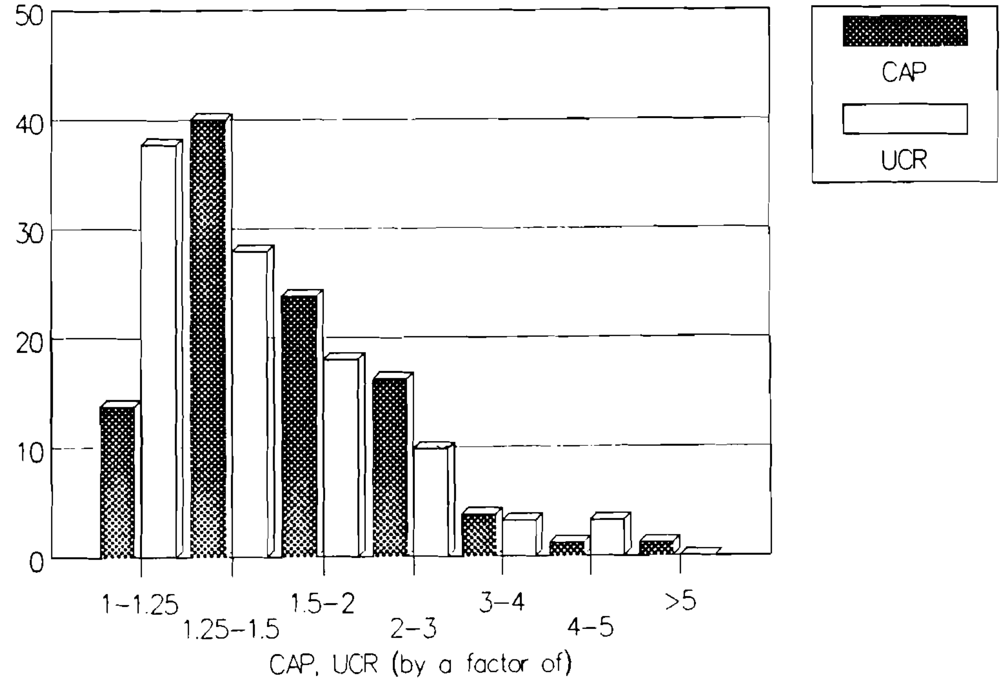

Figure 6. FMS distribution (%) over capacity utilization increase (CAP) and unit cost reduction (UCR).

reported, the increase ranged from 5% to 50% (see *Figure 6*, only 18 FMS achieved the increases higher than 100%.

Another way of fixed capital saving is the reduction of floor space and, consequently, construction costs. Due to the lower number of machines and the more compact storage and retrieval systems, the average floor space reduction of an FMS is by a factor of 3. But the most typical value of the indicator is between 1 and 2, which was reported in two thirds of the 56 cases.

As a result of savings in different cost elements – fixed capital, labor and operational expenses – and, higher FMS productivity and utilization there were noticeable unit cost reductions for the parts produced by 61 machining FMS. The majority of the cases (65%) demonstrated UCR from 5 to 33% (see *Figure 6*). Greater than 50% reductions were reported in 10 cases, mainly for the systems where this advantage was mentioned as a main target of FMS implementation.

As a result of the FMS distribution analysis – as well as consideration of some the most advanced systems records – we propose the following "portrait" of a typical "FMS-1988", with some assessment of the perspective directions of FMS development.

"Portrait" of "FMS-88" and perspectives (in brackets)

1. Country: Japan, USA, FRG (Scandinavian, Eastern and NI countries)
2. Industry: transportation equipment, machinery (electronics)
3. Area of application: metal-cutting (assembly)
4. Type of product: prismatic parts (sheet-metal and non-metals)
5. Number of NC-machines: 3-4 (the same + 20-25 NCMT family)
6. Number of machining centers: 2-4 (6-8)
7. Number of robots: 1 (4-6 or 30-40 for assembly)
8. Transportation system: AGV (the same + in-process control)

9. Investments: 1-4 mill. US$ (the same + super systems)
10. Pay-back time: 3-4 years (3)
11. Number of product variants: 50 (100)
12. Average batch size: 50-100 (20-50)
13. Lead time reduction: 2-3 (3-5)
14. Work-in-progress reduction: 2-3 (4-5)
15. Inventories reduction: 2 (4-5)
16. Personnel reduction: 2-3 (3-4)
17. Number of machines reduction: 2-4 (the same)
18. Floor space reduction: 2 (the same)
19. Capacity utilization increase: 1.4 (2)
20. Unit cost reduction: 1.25-1.5 (2)

Interdependencies of FMS Indicators

It is natural that almost all the FMS indicators are interrelated. For FMS diffusion modeling and forecasting purposes, it is important to know not only the directions of relationships, but their quantitative parameters too. For example, it is theoretically obvious, that a technically more complex system must cost more too, and it is statistically confirmed by our data. But the TC - INV relation significantly depends on the country, where the FMS is installed. For the countries main FMS users, we have obtained the following parameters of regression between investments (INV) and technical complexity indicators (TC):

$$\begin{array}{lclcll}
\mathrm{INV} & = & 1.56 & + & 0.665\ \mathrm{TC} & \text{- France} \\
 & & & & (2.3) & \\
\mathrm{INV} & = & 1.18 & + & 0.937\ \mathrm{TC} & \text{- the FRG} \\
 & & & & (3.0) & \\
\mathrm{INV} & = & -0.44 & + & 0.940\ \mathrm{TC} & \text{- Japan} \\
 & & & & (7.2) & \\
\mathrm{INV} & = & -1.67 & + & 1.470\ \mathrm{TC} & \text{- the UK} \\
 & & & & (8.6) & \\
\mathrm{INV} & = & 0.70 & + & 1.820\ \mathrm{TC} & \text{- the USA} \\
 & & & & (6.7) &
\end{array}$$

t-statistics is shown in the brackets.

The relatively high investment cost of the US FMS could be explained in four ways. The first difference is due to different systems of calculation. FMS in the USA are usually bought as turnkey systems, while in other countries some investment components are covered within the company (e.g. software or supporting systems development) and not included in the investment cost.

The second reason is the installation strategy. Japanese companies spend up to 1-2 years over extremely careful pre-installation planning, choosing optimal FMS architectures and future operational modes. The third reason is connected with the use of super expensive FMS by military oriented giants of the US and UK industries: LTV, General Dynamics, Lockheed, McDonnel-Douglas, British Aerospace, Rolls-Royce - where FMS cost does not play a critical role.

The fourth reason could be 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 USA, quality improvement plays a more important role. The US FMS are more expensive (having the same TC), due to the high share of in-process quality

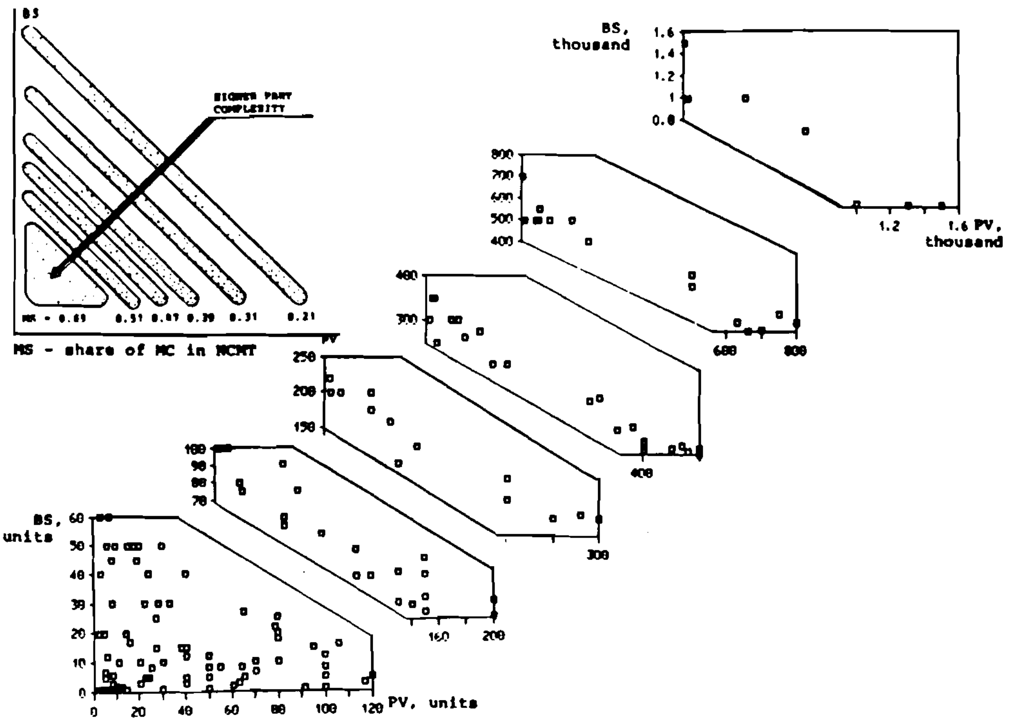

Figure 7. Batch size (BS) versus product variation (PV) - FMS flexibility by part complexities.

control sub-systems, while their use in other countries is relatively rare.

Due to a very high variation of both flexibility indicators – number of product variants (PV) and average batch size (BS) – it is difficult to represent their correlation by one graph. Clustering the cloud of points we found that there were several distinct strips where BS versus PV points were allocated, see *Figure 7*. All the strips show negative slopes. Looking through the cases allocated within each strip we found that the main factor behind such clustering could be the technical complexity of the parts produced by the FMS.

As there is no direct indicator of parts complexity in the bank, we have chosen the MC/NCMT relation as a substitute for the indicator. The higher share of multifunctional machining centers (usually machining several surfaces at once), in the total number of NC-machine tools corresponds to a higher part complexity. The estimates of the average shares (MS) for each strip showed a very strong gradient (see the window in *Figure 7*), proving the assumption statistically. The lower left corner includes the cases where the moderate batch size is explained by the demand structure, and the low number of products is connected with very high complexity of parts (number of surfaces developed, accuracy of development, etc.). The upper left corner of the graph demonstrates the FMS replacing production lines for big batches production of a rather limited number of parts. FMS for simple parts production are allocated in the lower right corner.

Japanese FMS have the highest flexibility (measured as an average PV/BS ratio), followed by the USA, FRG and UK. Higher flexibility provides a bigger lead time reduction, which is 20% larger in Japan, than in the USA, and about 50 % larger than in the FRG and UK. 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), see *Figure 8*.

This is true for lead times, work-in-progress, and personnel reductions. The analogous assessment made for flexibility, measured by a PV*BS product, shows a definite decrease of efficiency indicators (LTR and WIP) when we move from FMS producing technically complex

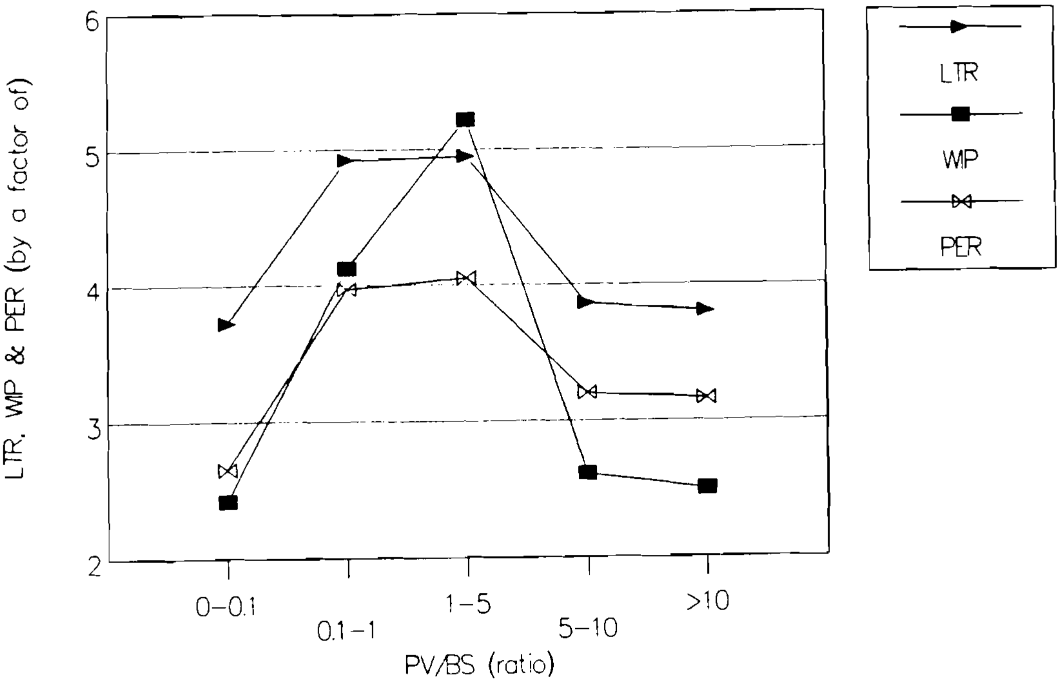

Figure 8. Lead time (LTR), work-in-progress (WIP) and personnel (PER) reductions versus PV/BS ratio.

parts, to systems producing a lot of simple parts in large batches.

Pay-back time could be considered the most important indicator of FMS economic efficiency. All the other FMS advantages are focused in it. Of course, there are some national differences in PBT calculation, but the sample containing 89 machining FMS where PBT has been reported is large enough to eliminate such national disturbances. Contrary to classical considerations, in a PBT proportionality to investment cost, we found that this relation is nonlinear for the FMS data. Systems costing from 5 to 8 mill. US $ have the longest pay-back time (5.3 years on average). A similar curve for PBT versus FMS technical complexity index (TC), is shown in *Figure 9*, and proves that the systems with medium complexity have the lowest economic efficiency.

These results could be explained in two ways. First, simple and cheap FMS usually do not use expensive flexible subsystems, like AGV, ASRS, in-progress quality control. They use relatively simple software and have already passed through a learning curve. On the other hand, the share of the computerized sub-systems in the cost of big FMS is relatively low. The use of medium size FMS without supplementary sub-systems is inefficient, but the cost of such subsystems and the necessary software is relatively high, and increases the PBT of the FMS.

Another explanation is connected with the mode of operation. Both polar groups (cheap and expensive FMS) are usually not very flexible in the term of product variation. For example, the systems with TC = 1–3 the average number of product variants does not exceed 50, these produce a limited number of parts in moderate batch sizes, a classical FMS niche. But the most technically complex FMS substitute for transfer lines in big batch production, and produce rather limited numbers of products. This is a new FMS niche. For the systems of high complexity, we also found that they demonstrate the highest values of capacity utilization increases (by a factor of 2), as well as reductions in the number of employed personnel and the number of machines used (by a factor of 4.9 and 5.5, respectively). Their average batch size is twice as large than in

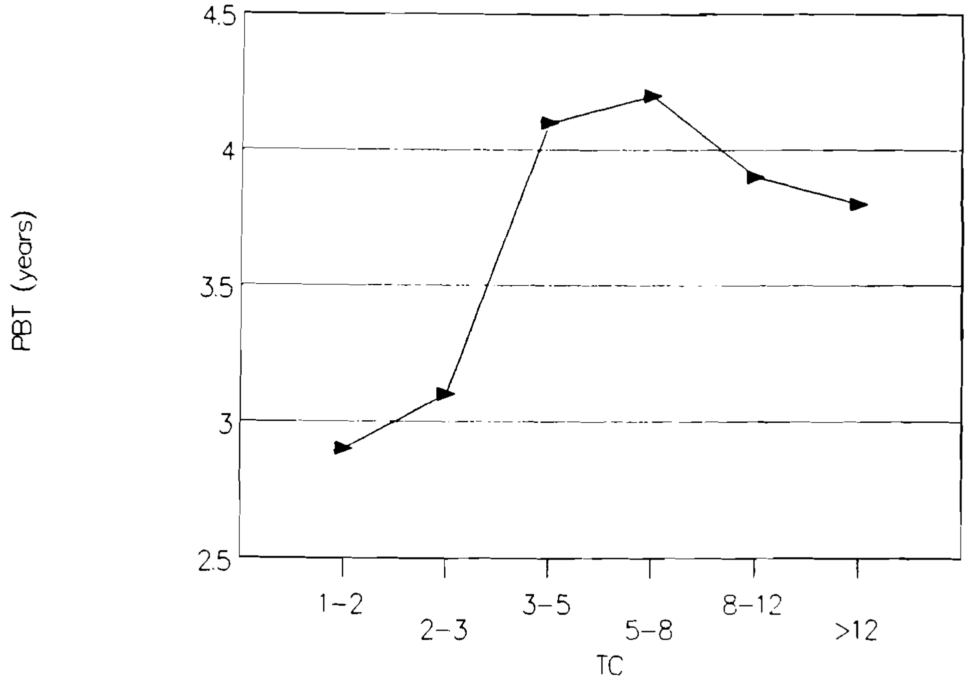

Figure 9. Pay-back time (PBT) versus technical complexity (TC).

the sample as a whole.

Regression analysis confirms that there are four main factors providing shorter pay-back time are as follows: lead time, work-in-progress, personnel reductions and higher operation rates. Their impacts depend on FMS implementations targets. The lead time reduction is provided, first of all, by the reduction of set-up time. Systems with PBT = 1-2 years are used three shifts a day, while the systems with PBT = 4 and more years are used during 2.5 shifts on average.

FMS Development Tendencies

The general FMS distribution by the year of installation, confirms that the real FMS penetration into the industry began in the 1980s, though the first implementations were reported before 1970. We have again 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 10*. 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. The same tendencies are demonstrated in the US and Japanese cases. The former passed a technical complexity peak in 1986, while the latter ones had passed it in 1983.

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 10*. 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.

In the 1980's the tendency towards a higher technical complexity encountered a number of

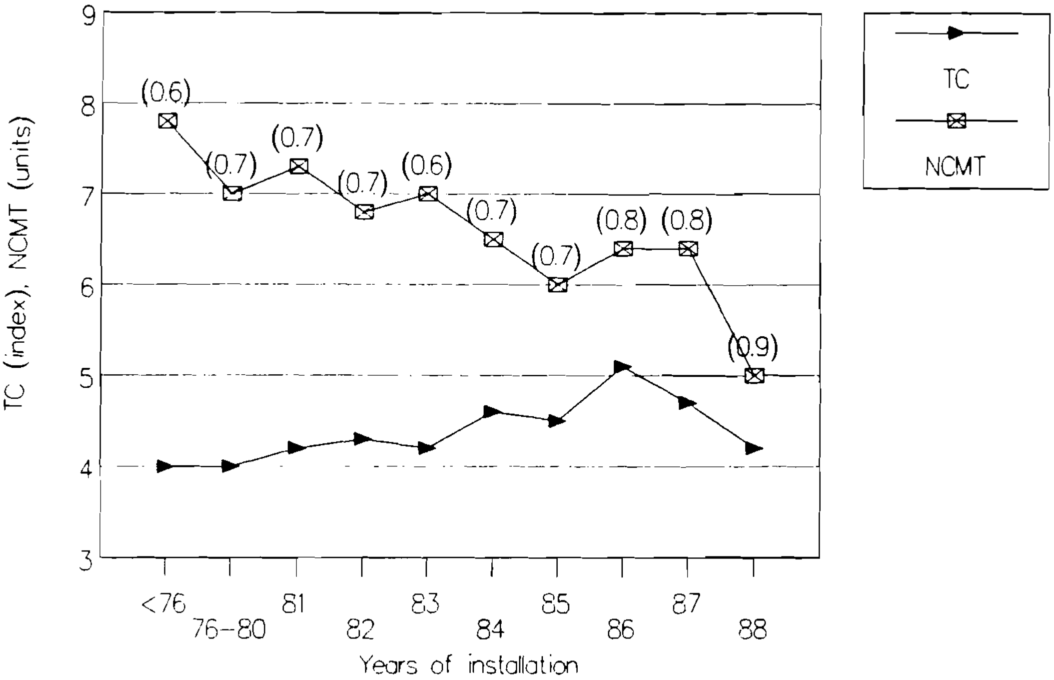

Figure 10. Technical complexity (TC) and NCMT trends. In brackets - MC/NCMT ratio.

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. In the 1980's a lot of 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.

The FMS investment cost could be treated as a stable cost equal to 5-6 mill. US $. 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 mill. 1967 $. This process is a result of the growing sophistication of FMS until the middle of the 1980's, compensated for by a relative price decrease for its main elements, especially computer hardware.

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 11*.

Because of a shortage of FMS advantage indicators we are able to assess the trends only for aggregated time intervals. The really strong growth in lead time (LTR) and work-in-progress (WIP) reductions is clear, especially from the beginning of the 1980s. Finally, FMS implementation led to LTR reduction by 80-90% and to WIP reduction by 75-80% in 1985-88.

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, number of machines 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 were 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

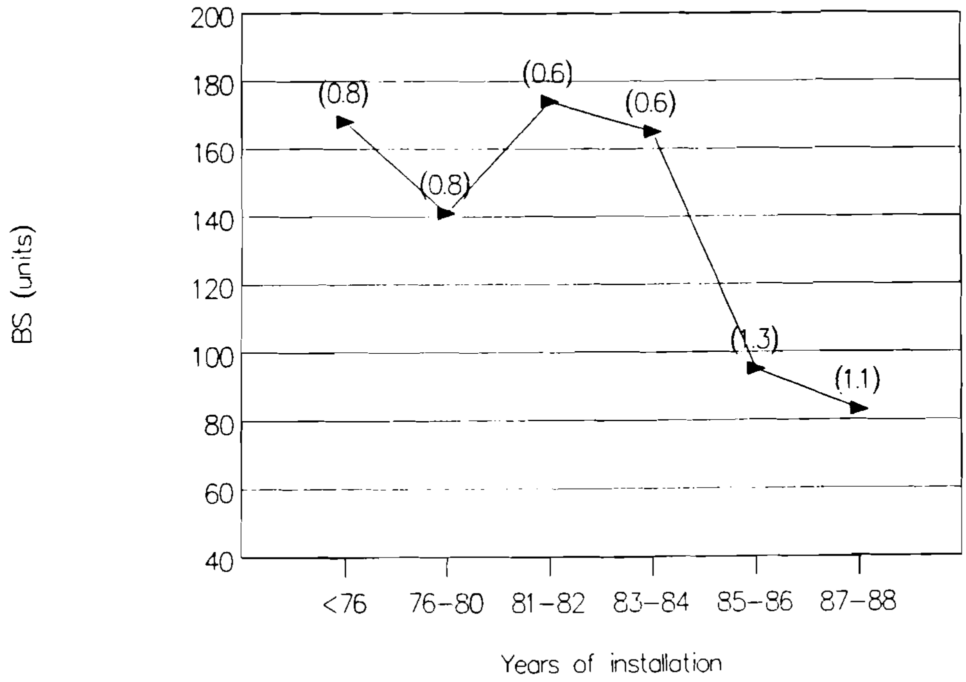

Figure 11. Average batch size (BS) trend, PV/BS ratio is in brackets.

played a less important role, and the cost of a further increase of the indicator made additional labor savings unreasonable.

The unit cost reduction (UCR) are 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 conventional technology, later it dropped to 50-65%. As a result of FMS development and improved usage, especially connected with better management and higher flexibility, the payback time displayed a distinct tendency to decrease: from 4.1 to 3.5 years in 1987-88.

Conclusions

FMS diffusion is expanding rapidly in the 1980s, and new industries (electronics, instruments) as well as 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 or rotational parts in non-electrical and electrical machinery, as well as in the production of transportation equipment.

Each new FMS generation had a higher technical complexity than its predecessor, due to more machining centers and robots being 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 reaching a peak, a certain stabilization of sophistication processes is observable. We find that one of the main reasons for such a change is that FMS left the embryonic phase of their introduction. The first adopters had passed through a learning curve and FMS appeared on the general market. At this stage the FMS users club became wider and wider, 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 the technical factors, which were more important earlier.

Looking through the trends shown above one can see that there were two significant periods where the relative advantages of FMS began to be clear, in the late 1970's/early 1980's, and in 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.

The quantitative analysis of different aspects of FMS diffusion in the world covered in this chapter, forms the background for a later chapter dealing with the forecasting of CIM penetration in the metal-working industries.

International Comparisons of FMS Diffusion: the USSR, the UK, and the FRG

by

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International Comparisons of FMS Diffusion: the USSR, the UK, and the F.R.G.

Roman Sheinin

1. Introduction

During the past few years information on FMS installations throughout the world has been collected and published by IIASA's Computer Integrated Manufacturing (CIM) Project. The analysis of the process of FMS development based on this data can be found elsewhere [1]. The aim of this paper is to try to discover patterns of FMS diffusion in three particular countries: the FRG, UK, and the USSR, the intention behind to add further analysis to that given in [1].

These countries have been selected as the object of analysis because of their similarity from the point of view of FMS diffusion processes (see Fig. 1). The second reason was connected with experts opinions which confirmed that available data on these countries were more complete than in many other countries, for example the sheer size and complexity of the United States or Japanese markets probably means that the agregate data analysis currently, is incomplete.

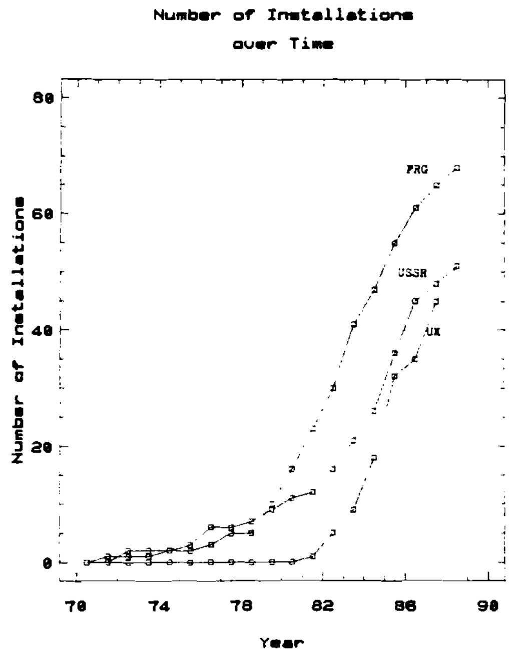
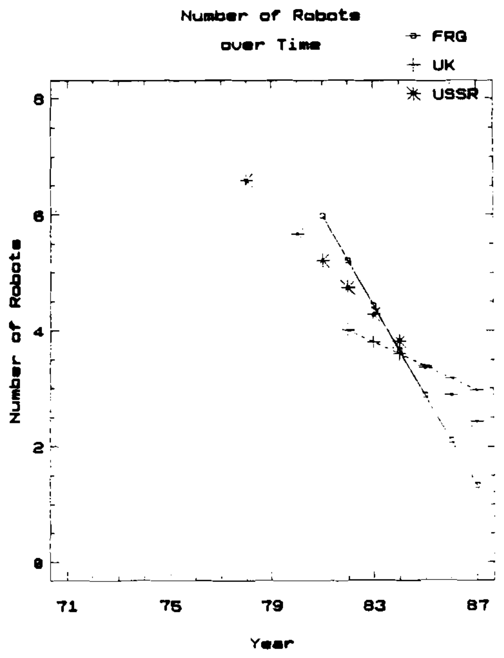


Figure 1



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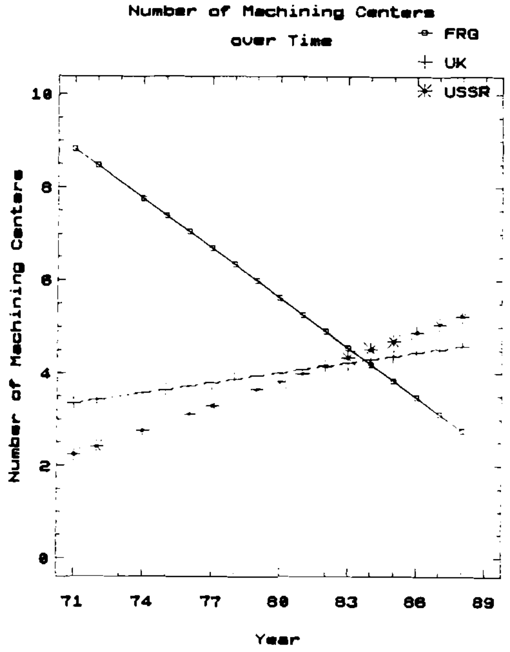

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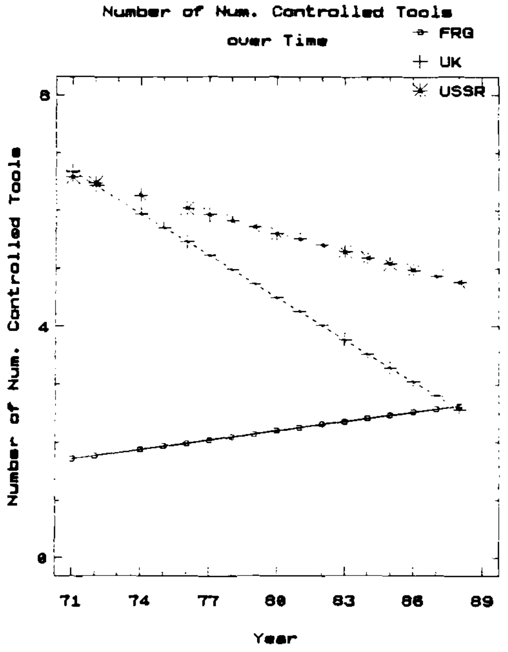


Figure 4

2. Method of analysis

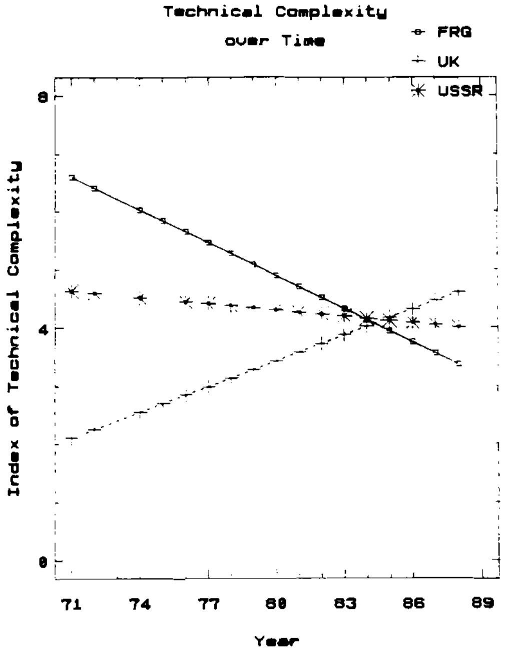
The main goal of the analysis was to derive some conclusions on how principal features or aspects of FMS installations in a given country are changing over time. In order to do this following steps were fulfilled.

The data on the dynamics of particular aspects of FMS installations in a particular country were smoothed by applying linear regression analysis. All three graphs were then plotted simultaneously to reveal differences or similarities of relevant diffusion processes. The linear trend of diffusion was extracted by linear regression and should, of course, be treated mostly as a qualitative and not a quantitative outcome of the smoothing process.

3. Technical complexity

The technical production complexity of an FMS can be described by the number of robots or the number of machining centers or the number of numerically controlled machine tools or with the help of an artificial index which combines all these measures. All four parameters were used (Fig. 2-5). One can see that the main tendency is a decrease of technical complexity over time in both the FRG and the USSR and the increase of this characteristic in the UK.

At the same time the number of robots per system is decreasing in all three countries. The number of machining centers is also decreasing in the FRG, though increasing in the USSR also



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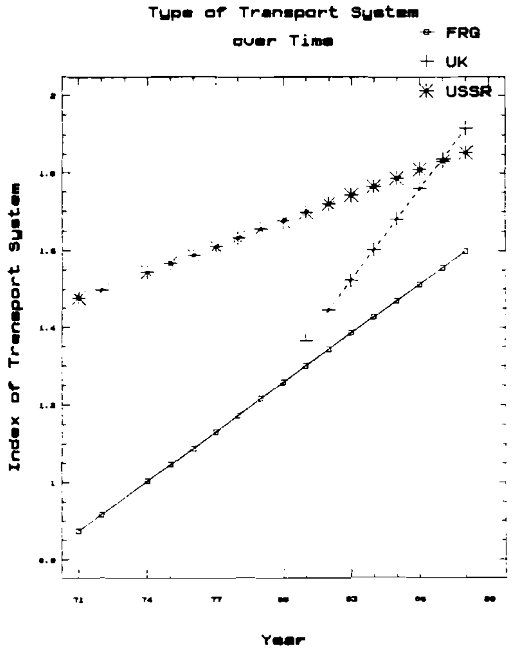

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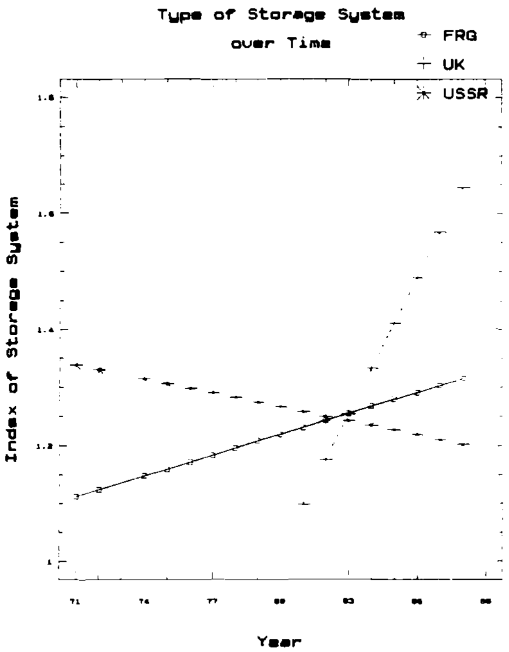

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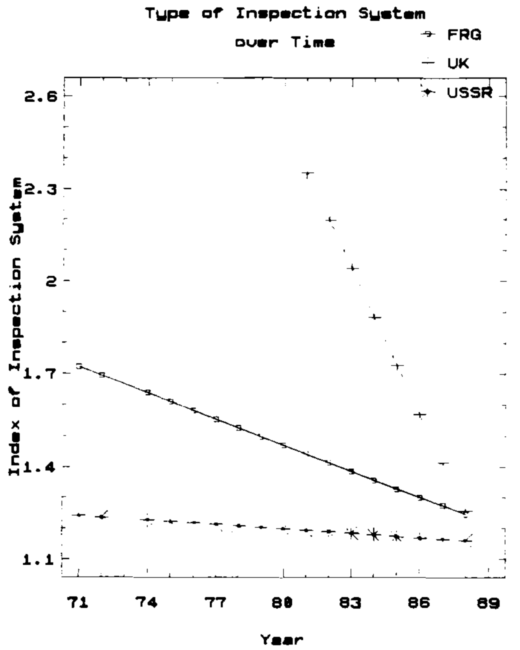

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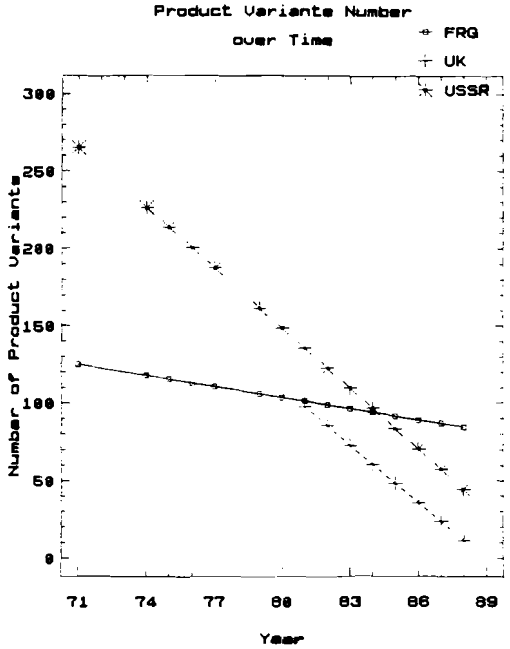

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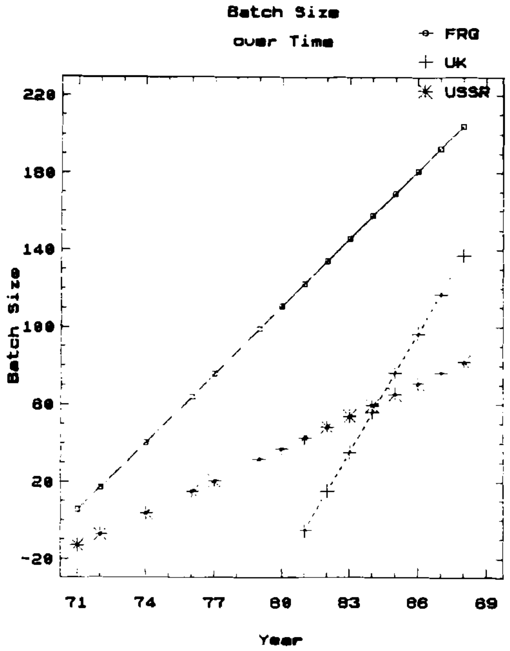
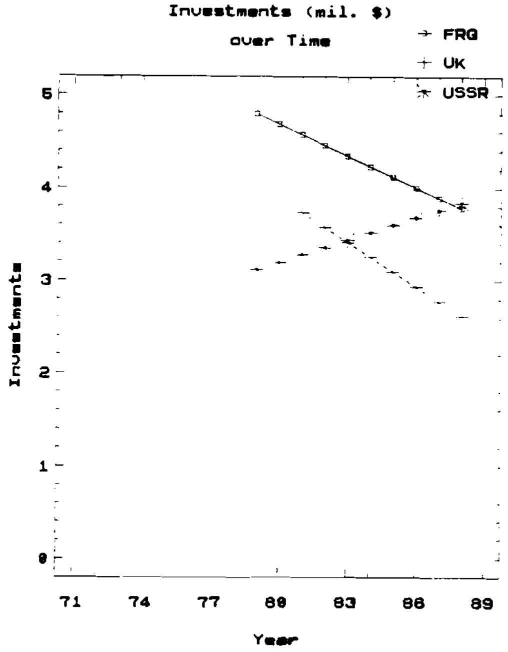


Figure 10



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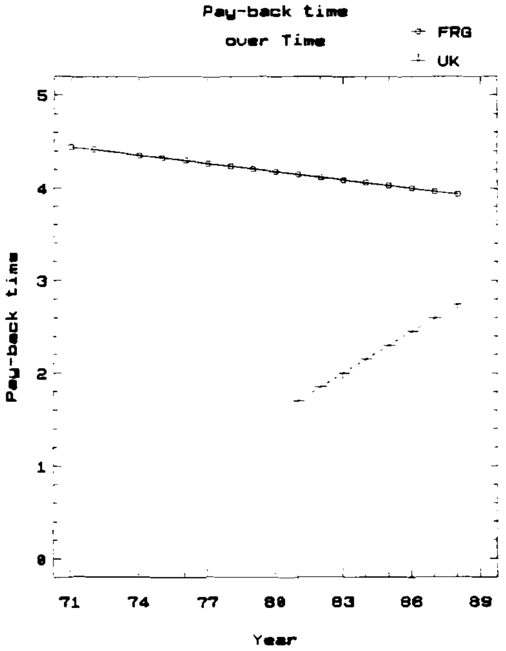

Figure 12

is almost constant in the UK. The number of NC machines per system is decreasing both in the UK and the USSR, but increasing in the FRG. An overall assessment of technical complexity dynamics is given with the help of an artificial index (see Fig. 5). This graph demonstrates the increase of technical complexity only in the UK.

Other aspects of technical complexity of FMS's are the types of transport, storage, and inspection systems utilised (Figs. 6-8). Respective index's were designed incorporating the increase of the level of complexity of each system.

The sophistication of transfer systems is increasing in all three countries (Fig. 6), while the level of development of storage systems is increasing significantly in the UK, but only slightly in the FRG (Fig. 7). The sophistication of inspection systems is decreasing in all three countries (Fig. 8).

4. Flexibility

Threre are two main measures of flexibility: the number of product variants which can be produced by particular FMS and the batch size. The greater product variants that can be manufacturing and the smaller batch sizes are, the more flexible the FMS is likely to be. Both measures demonstrate rather clearly that the flexibility of FMS installations are decreasing over time in all three countries (Fig. 9, 10). The dynamic of this process agrees with the dynamic of technical complexity: both properties are becoming less "advanced". So the following conclusion could be advanced: the diffusion of FMS in the FRG and the USSR has led to the introduction of relatively less flexible and less sophisticated FMS. The peculiarity of FMS diffusion in the UK is that the decrease of flexibility is combined with an increase of technical complexity, largely because of a rapid increase of sophistication of both transfer and storage systems (Fig. 6, 7).

5. Economic data

Available data provides a possibility of analysing only two economic parameters in depth: investment cost and pay-back time (Fig. 11, 12). It is

nor surprising to discover that FMS's are becoming less expensive in both the FRG and the UK. This fact agrees with the idea that technical complexity and flexibility are main factors which determine investment cost. The situation in the USSR is rather different and should be analysed in greater detail in future research.

Pay-back time is increasing in the UK while in the FRG this parameter relatively is unchanging. The former confirms the conclusion obtained earliar that greater flexibility is often connected with longer pay-back times.

6. Utilization and relative advantages of FMS

The level of FMS utilization is increasing in all three countries with the most rapid changes occuring in the FRG and the UK (Fig. 13). In both countries the normal mode of operation of FMS is usually two to three shifts per day.

One of the most important impacts of the use of FMS use is the personnel reductions (Fig. 14). This demonstrates that the respective parameter is almost unchanging in the USSR and is increasing both in the FRG and the UK, with the most rapid changes occuring in the latter case. It seems reasonable to assume that this is determined by the higher level of sophistication of service systems (transportation and storage systems).

7. Conclusion

As far as available data permits us to draw some conclusions they could be stated as following. The diffusion of FMS in FRG and USSR is revealed in a greater share of relatively less flexible and less sophisticated FMS. The peculiarity of FMS diffusion in the UK is that the decrease of flexibility does combine with a increase of technical complexity resulting from a rapid increase of sophistication of transport and storage systems. FMS are becoming less expensive in both the FRG and the UK.

The level of FMS utilization is increasing in all three countries with the most rapid changes occuring in the FRG and the UK . In both countries FMS are now normally used for three shifts per day. Personnel fluctuations are almost non-existant

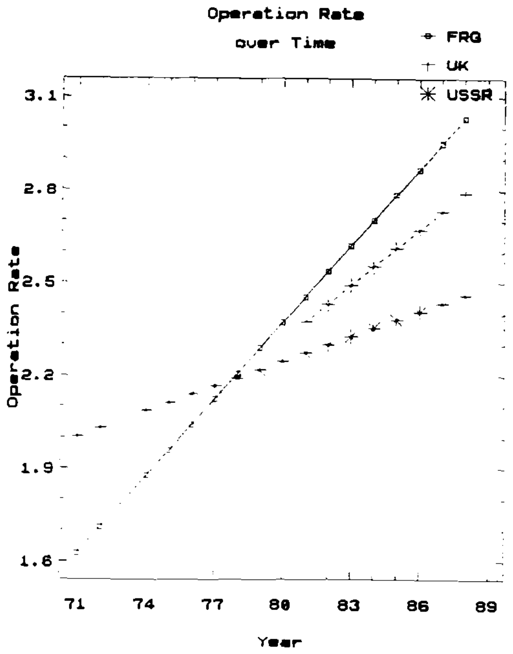

Figure 13

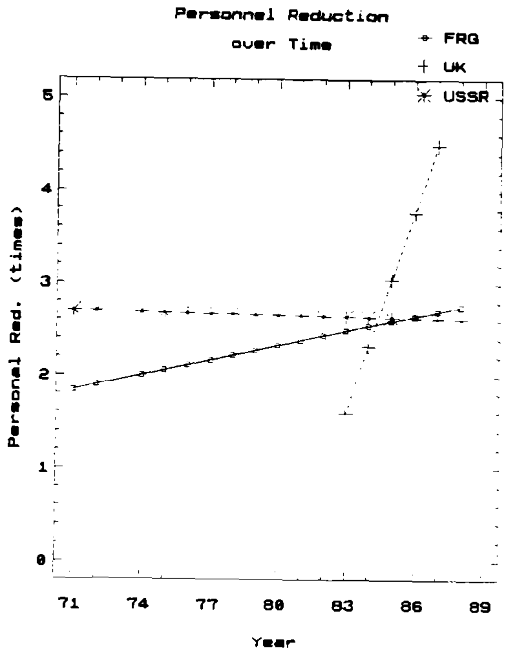

Figure 14

in the USSR, but in both the FRG and the UK there has been job-loss with the most rapid change occurring in the latter country.

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Why is Diffusion so Slow if the Technology is so Good?

by

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Why is Diffusion So Slow if the Technology is So Good?

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This paper focuses on four areas which describe and explain the diffusion of advanced manufacturing technology and the factors which shape its effective use. These are: i) the strategic forces shaping manufacturing world-wide; ii) general factors which determine technology diffusion; iii) some of the patterns of use of advanced manufacturing technology and some constraints on diffusion; and iv) the role of government policy.

1. Strategic Forces in Manufacturing: New Forms of Corporate Organisation

Two major forces are driving corporate re-organisation in the 1990s: world-wide economic competition and co-operation due to rapid declines in communications and computing costs, and the re-structuring of manufacturing and service activities under the impact of this new competition. These forces have made firms concentrate on new products, better quality, production flexibility and all-round improvements in operations to survive and grow. This in turn has made effective and efficient use of advanced manufacturing technology (AMT -- essentially computer- or microelectronically-controlled equipment, comprising FMS, FMC, CAD and individual equipment) a key determinant of competitiveness.

1.1 Challenges driving corporate re-organisation

Firms are faced with a series of global challenges. They must:

- Meet new competition at global level;
- Become more adaptable commercially and technologically;
- Compete in a wider range of geographical markets;
- Compete in a wider range of product markets;
- Operate shorter product cycles and become generally more flexible;
- Re-organise relations with local suppliers and customers.

The challenges are multi-dimensional, not only shifting and modifying the activities in which firms are operating but also fundamentally questioning their organisational structures.

Responses too must be multi-dimensional. New forms of organisation are not permanent, but are part of long term evolution and transformation. Some of the changes and aims currently being undertaken by manufacturing firms are laid out in Table 1. These list the transition from stable hierarchical, divisional structures with slowly-changing products operating in a few geographical markets towards more flexible, adaptable and responsive structures.

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* The views expressed in this paper are not necessarily those of the OECD or of its member countries. The author wishes to acknowledge recent work with François Chesnais, OECD, on which this paper partly draws.

Firms have changed their management and investment priorities to meet these challenges. Table 2 displays a typical set of management and investment priorities of medium-sized firms. Management priorities are firmly anchored to intangible investments (training, marketing, R&D, organisation) necessary to grapple with new competitive forces. Human resources get high priority. Market and product development, management and re-organisation to improve production and achieve growth all have high priority. Despite the importance of intangible investment in management priorities, investment often focuses on expanding physical production capacity and market access through external acquisitions and joint ventures and through internal expansion investment. Training, commercial development, design and other intangible investments provide the necessary underlying support in investment strategies, but are often not be considered as investments due to the conventions of accountancy.

All of these challenges and priorities have led firms to re-structure and to re-position themselves to achieve new economies of scale and increased economies of scope. These re-structuring and re-organisation efforts are driven by the need to become more efficient and more competitive.

1.2 Corporate organisation: Internal hierarchies and external markets

The organisational shifts now taking place can be described in terms of the relative efficiencies and disciplines of hierarchies internal to firms and markets external to firms, and how these hierarchies and markets are organised by firms to achieve economies of scale and economies of scope. The force which drove firms to vertically integrate operations internally from raw materials through to marketing and servicing final products was the constant search for economies of scale. This also led firms to operate in foreign markets and to organise stable global oligopolies in many products and industries.

However, there are diseconomies of scale in organising production and distribution internally on a large scale, which become particularly apparent when there are sufficient competitors and new entrants to make oligopolistic market organisation unstable. Extended hierarchical organisation does not necessarily deliver the best new product and market solutions or maximum flexibility. The search now is to find a new set of organisational forms which can meet new competitive challenges. These are shifting the balance between traditional internal and external ways of organising business, covering many of the functions of firms which were organised internally and which can now potentially be organised through external markets.

Some of the shifts in corporate organisation commonly underway are:

-- The move to decentralised, responsive market-driven structures and parallel changes in work organisation. The classic production system was based on vertical integration, hierarchical control, very fine division of labour and repetitive tasks ("Taylorist" organisation). The potential of computer-controlled equipment to flexibly perform many tasks and the challenge of organising development, production and delivery to use this potential is changing the organisation of manufacturing and services. Operational responsibility is pushed down to the shop-floor, akin to the push for greater external supply of components and services. This effectively provides a non-hierarchical "market" for production within large firms, based on greater delegation of responsibility in organising work, ensuring quality and performing preventive maintenance and other tasks, with flatter hierarchies and less top-down control.

-- Using the external discipline of markets to provide functions, services and products formerly produced internally in large firms. This includes new forms of "quasi-integration" which makes suppliers responsible for component and sub-assembly development, design, production and delivery. Suppliers gain economies of scale by integrating many functions over a greater volume of similar products, and economies of scope, particularly through the use of flexible manufacturing technology, and in development and design. Central organising firms shed dis-economies of scale arising from attempting to cover too many operations, from organising too many suppliers, and from replacing the market with complex hierarchical systems. This new kind of organisation enables economies of scale for the central organising firm in strategic planning, basic research, market development and financial operations; there appear to be economies of scale in global operations in these areas. This has been the basic organisational approach adopted by large Japanese firms, and increasingly by others.

The search for the best balance between internal and external organisation of operations has led to the appearance of a great deal of exploratory "networking" described in section 1.3. And difficulties in finding the most appropriate organisational forms to exploit AMT have been a major constraint on its diffusion, as discussed in section 3.4 below.

1.3 The growth of networking: integration and decentralisation

This very general term covers many phenomena, but essentially it covers the growth of a wide range of external links and co-operative arrangements which are used for exploration and development of functions previously internalised within firms. Three different developments capture the essential characteristics of networking.

(i) Operational and logistical networking

The operational success of large Japanese corporations in externalising many day-to-day operations to smaller suppliers with their own networks of sub-suppliers has inspired much study and emulation. Networking is coordinated by the central firm or (from the point of view of a sub-supplier) a series of firms. The central firm concentrates on operations which have long-term strategic value -- planning, research, market development, financial functions and control. The central firm retains responsibility for logistical and support activities for the whole group (infrastructure, overall technology development, human resource management). Central Japanese firms also provide much of the training in new technologies to their suppliers. Networking focuses on operations and logistics activities and achieves flexible economies of scale through "quasi-integration".

(ii) Technology-based networking

Many firms have built up dense national and international networks to explore and develop new technologies. These take many forms, ranging from broad research consortia and co-operatives in traditional industries (power generation), through development of generic technologies in semiconductors, opto-electronics and computer architecture, to focused joint arrangements with fewer members to develop individual products. These arrangements are partially externalising technology development activities to gain economies of scope (exploration in new and adjoining technological areas) and scale (reducing the unit cost of research by increasing size of research teams and sharing overheads), while retaining rights to subsequent operational exploitation.

Networking offers economies of scope to firms straddling a number of technologies -- for example where research is moving rapidly and is expensive in electronics, computing, communications systems. The potential attractiveness of R&D collaboration to spread costs, reduce duplication and widen opportunities has led many governments to subsidise such arrangements. However, there are considerable transactions and management costs involved, particularly if collaboration is not defined carefully and management and ownership rights and responsibilities are not exhaustively agreed upon in advance. These costs can outweigh the potential economies of scope for individual firms and economies of scale for all participants combined.

(iii) Consortia of small firms

Small firm networking is typified by the experience of small Italian firms with the organisation of loose consortia through to "quasi-integration" in industries such as textiles and engineering. Different kinds of economies can be reaped. In market-driven industries (textiles is the classic example), there are economies of scale in joint solutions to technology development (new materials, dyes), technology diffusion (process equipment) and marketing (trade fairs, export arrangements). There are also economies of scale through quasi-integration by a central firm to organise supply and sales by independent firms (the Benetton model). A different kind of joint economy has been reaped by small machinery-producing firms which band together to supply medium-sized integrated manufacturing systems (assembly, handling and control equipment). A combination of technology development activities and logistics, marketing and service activities are tackled through small firm networking.

In all of these examples networking is designed to gain economies of scale or scope by changing the balance between activities entirely within the firm and those which are performed externally. Intermediate activities are carried out within the partial control of individual firms but rely on market discipline provided by external collaborators. New forms of organisation have appeared which have some characteristics of integration combined with decentralisation, but with shared and more collaborative control. The effective use of AMT underpins some of the growth of these new structures.

2. Factors which determine technology diffusion

Diffusion of AMT is not simple and automatic. The adoption by other users after the original innovation encompasses a wide range of actions and conditions to begin to apply the technology and then to effectively reap economic benefits. Diffusion cannot be reduced to the process of introduction of new machinery onto the factory floor or into the office or the use of new intermediate goods. It must include the other vital steps taken to increase the economic efficiency with which the new technology is utilised. In the case of AMT these include the reorganisation of factory work and materials flows (such as just-in-time production programming) and improved management practices, in production, development and marketing.

Diffusion involves competition between new technologies and existing ones and the relative advantages of using competing technologies. Firms which have successfully mastered old technologies may face particular difficulties adapting their skill and knowledge base to successfully use of new ones. Delay in adoption under these conditions may well be rational (Metcalfe, 1990).

This section does not examine the relative merits of various attempts to describe patterns of diffusion (see Grübler, 1990, for a complete summary). Instead it discusses some of the general factors which have been invoked to describe and explain diffusion, before discussing some of the recent patterns of diffusion (section 3) and some of the implications for policy (section 4).

Four general factors are important in shaping the diffusion of AMT:

1. Relative costs between different kinds of investment;

2. Uncertainties related to future technological change and potential transformations in the technology supply available;

3. Technological inter-relatedness and indivisibilities and their role in the successful adoption of the new technology; and

4. Human capital and re-organisation requirements.

2.1 Costs of expansion and replacement investment

Adoption of new kinds of equipment can be delayed by the age of the existing capital stock and by the costs "sunk" in them. Investment carries new capital goods into use. But total investment comprises net investment and replacement investment, which differ in many respects. Investment in new technology can take place more quickly and earlier when investment is growing and less reliant on replacement. Net new investment is determined by new demand, and prices of the new product. Replacement investment is determined by the profitability of using new equipment compared with the profitability of running existing capital goods. Important factors bearing on profitability are operating costs and sunk costs (non-recoverable costs, for example if there is no market for the used capital good). Thus new equipment can be adopted: i) when there is net investment, or ii) when replacement investment is not blocked by sunk costs. In principle, replacement investment will go ahead when unit prices of the product manufactured with the new equipment minus unit operating costs (including some average of sunk costs) is greater than unit prices obtained for the product manufactured with the old equipment minus the unit operating costs of the old equipment.

In a simplified way, new equipment will be adopted at the same time by all potential users (one new technology replacing one old one) when:

1. All potential adopters face the the same levels of sunk costs, that is they have the same age and capacity structure of existing capital stock;

2. The profitability of using the new equipment exceeds that of the old.

These conditions are obviously difficult to meet -- partly explaining slow diffusion.

2.2 Timing, uncertainties and the role of suppliers

Timing crucially determines diffusion. The rate and extent of diffusion will be affected by expectations of the path and pace of future technical and market change. In the initial stages of diffusion, design may be fluid and technical or regulatory standards uncertain. Firms may expect that incremental innovations will improve performance, decrease cost and stabilise fundamental technical and regulatory specifications. Options may be added, making it suitable for different applications, increasing the range of potential users. Such expectations can slow adoption. Early adopters are risk-takers who, once numerous enough, create a "critical mass", by which late adopters can judge benefits. This is specially true for radical innovations like AMT that require a complete overhaul of skills and organisation. Adoption costs can be measured through evidence provided by a large number of users. The existence of this critical mass changes the cost/benefit potential because of the widening pool of skilled manpower, enhanced technical assistance and overall understanding of the new technology that comes from "learning by using".

Timing in adoption is also commanded by the strategies of firms supplying the new technology. Diffusion is the outcome of two processes: one is the creation of technology supply capacity, and the other is the development of demand. Moreover, it is the relative profitability of competing technologies, not their absolute profitability, which is important. This will change during the diffusion process with changes in the supply of competing technologies and in their applications environment. The reliable (or unreliable) supply of integrated FMS and CIM systems has been an important factor shaping and in many cases retarding diffusion.

2.3 Interrelatedness and indivisibilities

Production technologies are systems of multiple interdependent parts. An innovation which changes one part may be incompatible with the rest of the system and require corresponding and costly system changes to make it fit, particularly when systems and organisations cannot be sub-divided into smaller units or parts. These "costs of interrelatedness" must be taken into account along with initial capital costs in any rational investment decision. The magnitude of the indivisible investment necessary in a new technology and lack of compatibility with pre-existing technologies are major causes for delay in adoption. Technological innovations which can be adopted piecemeal within an industry diffuse faster (Metcalfe, 1990).

2.4 Technical expertise, training and managerial and work organisation

The notion of interrelatedness also applies to changes in skills and management competence which are needed to use a new technology, and to the abandonment of work practices, modes of organisation and habits of thought incompatible with it.

Many of the factors which promote diffusion are built on increasing intangible investments. Intangibles can be divided into two broad groups:

1. "Intangible investments in technology" comprising expenditures on R&D, patents and licences, design and engineering, to develop and improve the supply and use of technology, and

2. "Enabling intangible investments" comprising expenditures on worker

training, the information structure and the organisational structure of firms adopting new technologies.

This classification has been developed to distinguish intensities of different intangible investments during the product cycle. Marketing is treated separately and software acquisition is included with physical investment (OECD, 1990, and Scholz, 1990). These intangible investments are critical to develop the new technology and then realising eventual economic returns on investment.

3. Diffusion of AMT and constraints on diffusion

This section treats in some detail the patterns of use of computer-based automation equipment, some constraints on reaching high levels of diffusion and integration of equipment and reasons why diffusion is often relatively slow.

3.1 Diffusion of AMT

The diffusion of AMT is best appreciated by referring to special surveys or to data on particular technologies rather than aggregate investment data. Such surveys show that the extent of applications differs between different countries, between different industries and between firms of different sizes. They also show differences in the capabilities and features of different types of AMT as factors which determine the extent of applications.

The pattern and extent of use of different types of AMT is shaped by a number of interconnected factors, in particular:

1. The versatility of the technology for a wide range of applications;
2. The stage of development of the technology or the point reached in the respective technological trajectories. A new technology or a new combination of existing technologies will initially be applied in a small number of closely linked processes and industries in a few countries and subsequently spread more widely to other processes and industries. Simpler applications will come first, both between different types of equipment and within the same type of equipment;
3. The size of required investments and the length of pay-back periods;
4. Barriers or constraints on applications. These include shortages of trained manpower to install and operate new equipment, lack of software, problems in integrating new equipment into the existing work organisation and re-organising work.

Diffusion is well-advanced for relatively mature equipment which is widely applicable in standard applications and which does not have very high investment requirements. For programmable logic controllers or CNC machine tools diffusion densities are high and there are relatively small differences between the same industries in leading and lagging countries. UK survey data show that programmable logic controllers (PLCs) to control or monitor single pieces or series of process equipment, along with simple CAD stations, are the most widespread industrial application (Table 3). They have wide applicability and versatility in plants of all sizes and in industries of all kinds, are relatively simple and rugged, and have been available in industrial applications for twenty years after first being extensively applied in the automobile industry. CNCMTs, although they are not used as widely across different industries as PLCs or simple CAD stations, have also reached a stage of relatively mature diffusion, with less pronounced differences in density of use between leading and lagging countries once the structure of industry is taken into account. These relatively more mature technologies are also used extensively by small firms and factories, due to their adaptation to a wider variety of conditions and uses as they mature, and the demonstration effect flowing from the experience of the "critical mass" of successful users.

The potential to use different kinds of advanced equipment is different across industries, so that diffusion density varies across them. For example, the flexibility of CNC machine tools increases efficiencies and promotes extensive use, particularly in smaller firms and establishments, but usually within a limited set of metal shaping and forming industries (Tables 3 and 4). There is relatively little scope for extensive applications in other industries or functions. Computer numerical control applications for machine tools are now relatively widely diffused through using industries, and the level of applications is high in new investment. Further penetration of computer controls will depend on replacement of older equipment with new computer controlled machines and the possibilities of integrating these machines into broader systems, and by new investment in industries which are expanding.

Industrial diffusion of individual kinds of complex AMT equipment is also highly concentrated because of limited versatility, the relatively early point that they have reached on their technological trajectory, their interrelatedness with other kinds of equipment and reliance on different new kinds of skills and organisation. Industrial robots (the installed stock is shown in Table 5) have potential for widespread applications but so far have been mainly used in a limited range of repetitive tasks in larger firms in a few industries. Common tasks for robots are:

1. Process tasks such as spot- and arc-welding, surface coating or cutting, with the tool wielded by the robot, (automobile and engineering industries) -- 40-60 per cent of applications;

2. Handling tasks such as machine loading and unloading, moving work-pieces between machines, materials handling, packing (metals, engineering, plastics, synthetics) -- 20-40 per cent of applications;

3. Assembly operations (automobiles, electronics) -- 10-15 per cent of applications, but growing rapidly, and the most important application of advanced robots in Japan.

Most applications are in simpler process and handling tasks where there are relatively high volumes of throughput and low variations in patterns of movement. As a result, the largest number of industrial robots are found in the automobile and electronics industries, which have 40-60 per cent of total robots in most countries (see Table 6). By value the concentration of industrial robots in electronics and automobiles is higher, because these leading industries use robots in a more integrated fashion requiring greater reliability. In Japan, where robots are used to a much greater extent than in other countries, expenditures on advanced robots in the automobile industry were around 4 per cent of total manufacturing investment in machinery and equipment and more than 4 per cent in electronics/electrical machinery, miscellaneous transport, construction machinery and general machinery -- levels twice as high as the average. In industries with less scope for applications the investment share was usually less than one per cent.

Even within the specific limited set of applications of robots there are wide variations in robot capabilities and costs. Robots used for spot- and arc-welding, surface coating, gluing and sealing, and complex handling functions all require advanced microelectronic programmable controls and servo-mechanisms. Robots shipped to the electronics industry are more expensive than the average due to the relatively complex tasks (surface mounting, assembly, handling) and the high levels of reliability required in high volume production. They are on average at least 5 times more expensive than simple loading and unloading robots used in the plastics and synthetics industry. The most expensive robots go to industries which are not yet major users, where applications are still in an exploratory stage, requiring more complex or advanced functions, where there are not yet economies of standardisation or scale on the supply side, and where the modes of use and patterns of organisation have not yet been thoroughly worked out.

More advanced and more highly integrated applications are initially limited to a small group of countries and industries. CAD/CAM and integrated advanced manufacturing systems are concentrated in a few countries, industries, and large firms, although wider diffusion may ultimately be rapid. Sweden and Japan had the lead in the mid-1980s in applications of flexible manufacturing systems, which require integration of different kinds of equipment into a functional networked unit. Swedish firms had almost double the level of UK applications of centralised machine control, integrated process control and automated handling and storage, whereas in less integrated applications differences were usually smaller when measured on the same basis. And in large-scale factory automation systems, where problems of organisation and integration are most critical, there is a similar high density of systems in only a few countries and a few industries due to the complexity of installation and management. (See industry distribution of FMS/FMC in Canada in Table 4.)

Manufacturing communications systems (local area networks -- LANS) used for connecting different pieces of equipment into integrated systems and process testing and inspection equipment, are widely applied in flow-process industries and less heavily concentrated only in metal working and engineering industries than for example industrial robots. For example, in Canada and other resource-based economies (Australia, Finland) the paper and allied industries, primary metals and chemicals are all major users of communications systems and advanced testing and monitoring equipment, and in some cases they have higher levels of use (more plants use this equipment) than the engineering industries (see Table 4). Japanese chemical and steel companies have been leaders in developing advanced opto-electronic process control technology, and some major steel companies are using this expertise to diversify into factory communications and automation activities. Nevertheless, because other kinds of AMT equipment are used to a lesser extent, these flow-process industries usually do not have the highest shares of total investment going into AMT.

The new diffusion challenges are to extend integration of individual pieces of equipment into a more complex whole. Here the constraints on more rapid diffusion lie on the supply side as much as on the slow formation of a market for complex and more expensive systems. The packaging of diverse hardware into functioning systems linked together by LANs has been slowed by the range of technologies and services to be assembled and provided by suppliers. Some suppliers have built on their own experience with automating their own plants to begin to supply equipment, but problems remain. These are particularly severe with interfaces between different kinds of systems, in providing software and the necessary tools and skills to re-organise firm structures so that they take advantage of the potential of integration.

3.2 Constraints on the use of advanced manufacturing technologies

Despite the potential benefits from investments in AMT applications a number of constraints have acted as a brake on their introduction. Over an extended period of time the most commonly cited are:

1. Lack of engineers and operations/maintenance staff with the necessary expertise;
2. Organisation problems and the challenges of re-organising production;
3. Technical problems with software and sensors;
4. A set of economic difficulties, such as high internal development and investment costs, problems planning and financing intangible investments and forecasting the value of qualitative benefits, and constraints in the external economic environment such as lack of development finance and the poor competitive outlook in some sectors.

These problems have persisted over time, with skill shortages being the most important, organisational and software problems increasing in importance and economic problems receding -- with the exception of investment financing and internal valuing/pricing of intangible investments. (See Figure 1 for the UK.)

Problems vary between firms of different size and different kinds of applications. Shortages of people with expertise are common for firms of all sizes in all countries. Organisational obstacles (production organisation and programming/software) are most common with advanced systems and shortages of technological skills with simpler ones. Technical problems are generally less common and experienced by the larger users, possibly because the complexity and ambition of applications were greater in larger firms. Shortages of investment/development finance are more common for smaller users.

These were established problems in 1983 in comparable surveys of disadvantages and problems facing firms introducing microelectronics (France, Germany, and the United Kingdom). Similar constraints have been continually observed in surveys in 1986-1989 in Australia, Austria, Denmark, Finland, Italy, Japan, New Zealand and Sweden. Systematic surveys in the United Kingdom over the 1981-1987 period confirmed that lack of people with expertise is the major problem. Difficulties of communications with sub-contractors, suppliers and customers have grown rapidly as the potential for wider communications and networking has been seen but not rapidly achieved. Problems with software and sensors have grown whereas economic and financial problems have receded.

3.3 Skill shortages and changing skill requirements

Skill shortages and changing skill requirements are the principal barriers to the introduction of new technologies into the work-place. However, skill shortages are often symptoms of a more complex set of problems involving:

1. Difficulties in adequately training multi-skilled workers with broad skill profiles,

2. Weaknesses in providing or finding specific technical skills, and

3. Poor human resource management and investment planning in firms.

The general lack of expertise cited by firms usually includes some combination of these problems. Shortages of skills in manufacturing, management and technology integration and market exploration are all critical impediments to successful applications. There is a particular need for new combinations of skills in production processes. Analysis of new technologies in automobile manufacturing shows an increased demand for workers with multiple skills, accompanied by a blurring of occupational distinctions and a reduction in the number of occupational categories. These multi-skilled workers provide the flexible work force needed to take full advantage of the more flexible production equipment that is technically possible.

3.4 Organisational constraints

Organisational problems are major impediments to new applications. Re-organisation of production must be set within the wider context of external and internal corporate organisation and networking discussed in sections 1.2 and 1.3. Successful applications require reorganisation of production and work practices, skill development and use, and perhaps of the entire enterprise. The extent of necessary change increases with the complexity and level of integration. New processes and products are often introduced together, and new product introduction requires extensive reorganisation of production and integration of product development into production planning.

The impact of technology on work organisation is not pre-determined by the technology itself. The technology interacts with other environmental factors, particularly the human resource strategy of the firm and external institutions. Surveys show that there is some management resistance to new applications just as there is some resistance from the shop floor, although these constraints are not as common as shortages of skills and increasing communications problems shown in Figure 1. Constraints on re-organisation are often related to concerns such as loss of management status and jobs as much as they are to the complexities of reorganisation necessary to apply new technologies. Alternative ways of implementing and using technologies have different implications for the economic and social welfare of workers and of firms, and these alternatives are being more thoroughly explored.

A study in the US automobile industry of the impact of different levels and kinds of automation on productivity (worker hours per automobile produced) and quality (defects per vehicle) showed that plants which adopted high levels of automated assembly without changing their human resource management strategies have not improved productivity or quality over plants which have not automated. Gains in productivity and quality have been experienced particularly in plants which have reformed human resource and labour management strategies (few job classifications, flexible work organisation, extensive communications), no matter whether there has been a moderate or more extensive technology upgrading strategy. Overall, productivity and quality are improved most by a strategy which combines more advanced technology with higher worker participation and higher skills. The next most productive arrangement combines lower technology with high worker participation and skill. Low skill and participation give poor results at all levels of technology (Osterman, 1990).

Tighter integration of production, higher speed and more costly consequences of errors have led to more "fragile" production systems. Greater work-place responsibility and monitoring, diagnostic and preventive maintenance skills are demanded. Employees must be better informed and understand all of the production process or business. Work teams which share responsibility and aims are more productive in many cases. Integration of development, production and delivery functions does not only occur through greater application of computing power and AMT, but more importantly through job re-design and re-organisation of tasks so that barriers between functions become more blurred and more highly integrated, with greater personnel mobility.

There are some general pointers to the kinds of organisation best suited to the use of AMT. High functional flexibility (internal mobility across tasks, flexible job design, training and re-training) and low numerical flexibility (low use of part-time and temporary employees, less attention to hiring and dismissals, less manipulation of working time) is more compatible with the use of AMT. Low functional flexibility and high numerical flexibility is less compatible. Some countries (Germany, Japan, Sweden) appear to be better placed to reap the benefits from wider use of AMT than others (UK, US), due to organisational and institutional traditions encouraging functional flexibility. See Figure 2.

Despite "national" patterns of organisation, firms also vary in the way that they deploy their human resources. Some have adopted many organisational innovations: work teams, quality of work and employment security for core employees in return for greater task flexibility and wider functional activities. Others employ essentially the same technology but are slower to adopt these organisational innovations. Overlain on this are national training, employment and industrial traditions -- the direction in countries such as Germany, Japan, and Sweden points towards greater skilling and greater flexibility in the organisation of work, and ultimately a greater likelihood of achieving the productivity potential inherent in new technologies.

3.5 Communications with sub-contractors and suppliers

Structural changes in the relations between firms and their sub-contractors are also an important organisational factor influencing the introduction of AMT. Sub-contracting can either be increased by AMT (due to better inter-firm relations, faster response times by sub-contractors, and greater flexibility associated with improved co-ordination between suppliers and customers) or decreased (due to greater internal flexibility in purchasing firms, enabling them to satisfy a larger share of their own internal markets). In some cases sub-contracting has diminished following introduction of highly integrated FMS in large leading firms. But patterns vary between industries.

Sub-contracting relations are being transformed by greater technical demands on sub-contractors to improve quality, specifications and design and to be more closely integrated into their customers' production cycle. Such demands are leading to major re-structuring of sub-contracting firms, and greater pressures for them to adopt advanced systems leading them into new forms of inter-firm networking and quasi-integration with leading firms.

3.6 Technical constraints

Technically possible best practice results are often difficult to attain, particularly by small firms. This is due to several factors. Software and sensor problems with computer-controlled equipment are commonly cited; these are much more important than economic difficulties or shortages of development finance for complex applications for example in Sweden and the UK. Firms are often confronted with broad technical problems involving cost, delivery, and reorganising relations with subcontractors, suppliers and customers. Furthermore, problems of technical compatibility and practicality are often under-estimated when planning new applications. Poor compatibility between new and existing technology is a major problem. Technical problems can also exist on the supply side -- the expertise to supply complex flexible manufacturing systems and provide the full range of hardware, software and services may be difficult to find within single firms or consortia.

3.7 Sources of technical information and assistance

Technical information to overcome constraints and to assist the development and implementation of new systems comes from a variety of sources. Links between users and suppliers are crucial to successful applications. Most users rely extensively on technology suppliers to provide them with operational systems. The role of the technological infrastructure (technological institutions, professional and industry associations, universities) in providing technical assistance varies between countries and it depends on the strength and depth of national technological institutions and private equipment suppliers. Although firms tend to use this infrastructure less frequently, when it is market-driven it can play a key role in providing long-term development assistance and consultancy and early information and advice.

3.8 Financial constraints

Applications of AMT equipment show many advantages for the investing firm -- better use of capital equipment, reduced levels of stock and work in progress, reduced time to design, build and deliver products, increased quality, and reductions in unit costs. But applications may encounter a range of financial constraints where firms are new and small and when new products are introduced with new AMT systems. Although average pay-back times are relatively short -- 2 years was often quoted -- cash-flow usually takes a longer time to become positive following investment, and 3-5 years is more realistic. Initial development and capital investment costs are high, as are necessary intangible investment costs, and long-term capital productivity improves only if equipment is carefully integrated into supply, production and delivery systems and if work organisation and firm structures are adapted. There are also risks with potentially high rates of obsolescence of new systems. Furthermore, conventional accounting may not value quality and flexibility in calculating pay-back, with unnecessary investment penalties and conservative lending attitudes towards small firms.

3.9 Summary of internal constraints on re-organisation of production

Overall, there are a number of constraints internal to the firm which determine success in investment. These are:

1. Human resource shortages at technical level and at the level of developing multi-skilled operations and maintenance personnel;

2. Organisational constraints, due to inadequate or ill-adapted internal structures (for example hierarchies which do not encourage skill-development and de-centralisation of management and

decision-making), and the necessity of changing the nature and structure of links with other firms;

3. Technical constraints in technical knowledge and internal resources such as minimum engineering and development capabilities and search mechanisms, or access to external resources through links with larger firms, technology suppliers or consultancy networks;

4. Supply-side problems, for example in the availability of complex computer integrated production systems.

4. Policy implications

Corporate strategies and new corporate structures are being built on greater use of AMT combined with increased inputs of intangible investments. Governments are beginning to focus on structural factors which determine investment in AMT, and to devise policies to improve the functioning of the technological infrastructure and increase complementary inputs of intangible investments. Specifically, some governments have devised policies to:

-- Promote the diffusion of AMT and improve its performance by providing information and extension services, improving technology supply to small firms, and by setting interface and technical standards;

-- Improve the general environment for organisational and structural flexibility, by reducing risks associated with new investment and raising skills and expertise.

Areas where governments have a role to play, particularly if services are organised through market driven consultancy or contract mechanisms are:

1. Information and awareness. One major problem when introducing new systems at early stages of diffusion is in obtaining information on the pitfalls associated with introduction and assessing the opportunities for applications in particular businesses. Small firms and lagging regions have the most acute problems, and although it can be difficult to reach target groups and deliver required services, governments can play an important local role.

2. Consulting services. A feature of some programmes has been the assistance given to small firms to explore the scope for applications by financing initial feasibility studies and encouraging the use of engineering, marketing and software consultancy or other means of building up competence. Initiatives vary widely but focus on: i) lowering the cost of initial exploration of AMT applications; and ii) providing market-driven services that explore a wide range of different kinds of applications.

3. Subsidising costs and spreading risks. Some of the cost hurdles faced by small and medium-sized firms can be overcome by encouraging the setting up of co-operatives to search for common applications solutions and to build broadly applicable demonstration units.

4. Training. A great deal of emphasis is being given to improving the skills of the workforce related to computerised manufacturing. Many

countries face multiple skills and training problems:

i) Long-established systems of post-compulsory firm-based training have declined in intake and relevance;

ii) Growing problems of: certification for the competences required for tomorrows' technologies, portability, and defining clear career paths and families of related training experiences;

iii) The work population in many countries is not expanding rapidly, and there is a growing shortage of skilled people at all levels.

In response to these problems there are a range of mixed firm/education agent/local authority/government initiatives which are exploring different kinds and levels of training.

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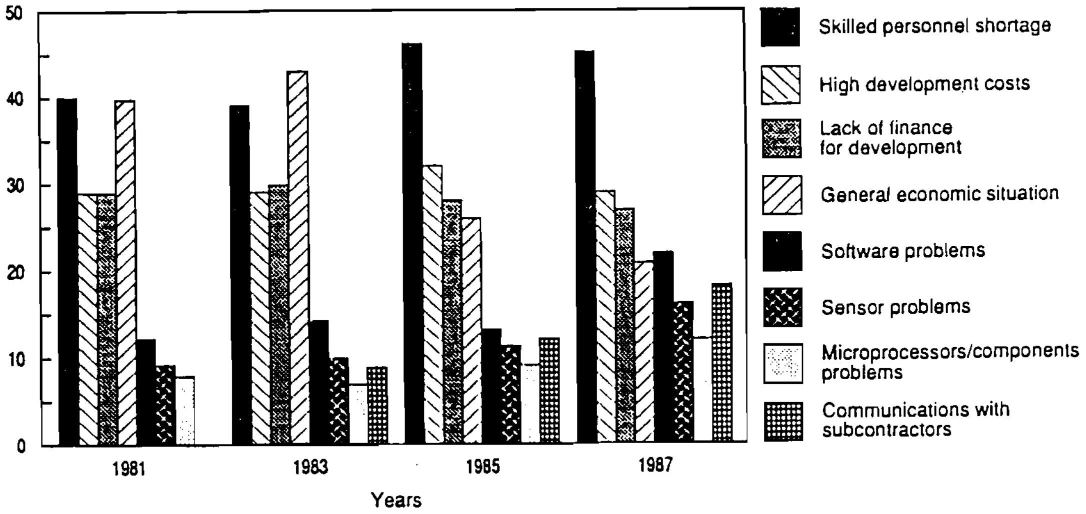
Figure 1

MAIN DIFFICULTIES OF MICROELECTRONIC USERS

(All UK manufacturing establishments using microelectronics : percentages)



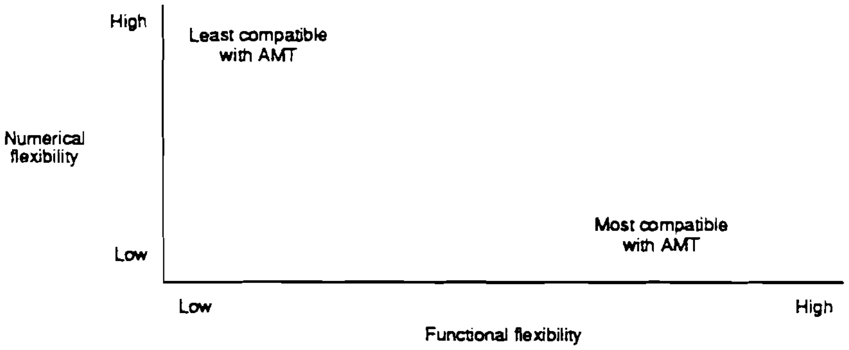
Source: Northcott, J. and Walling A., *The Impact of Microelectronics: Diffusion, Benefits and Problems in British Industry*, Policy Studies Institute, London, 1988.

Figure 2

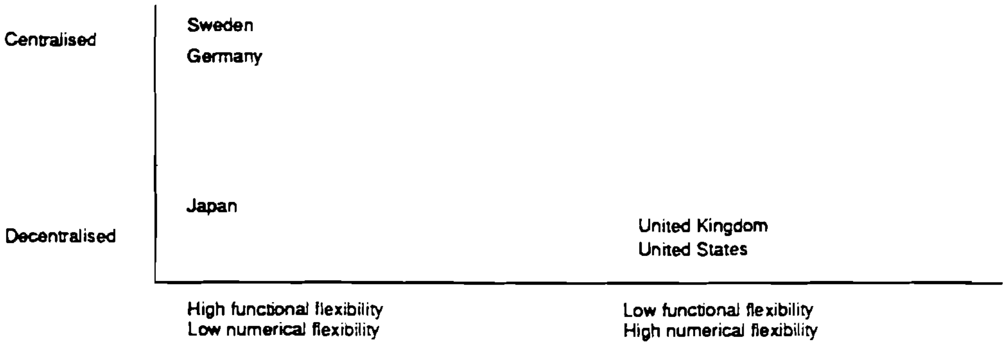
KEY ASPECTS OF LABOUR MARKET FLEXIBILITY

"Numerical" flexibility	"Functional" flexibility
Use of part-time and temporary employees Regulation of hiring/dismissals Organisation of working time	Internal mobility across tasks Job boundaries and job design Training and re-training

ORGANISATIONAL ADJUSTMENT TO AMT



LEVEL OF CENTRALISATION OF INDUSTRIAL RELATIONS AND THE MIX OF LABOUR MARKET FLEXIBILITY



The "level of centralisation of industrial relations" refers to the level of bargaining, the centralisation of labour and management organisations, and the state's role. The figure refers to established patterns of industrial relations and excludes systemic change.

Source: Vickery and Campbell. *op. cit*.

Table 1
Manufacturing in transition

Yesterday	Today	Aims/results
Volume, scale	Speed, response time	Rapid new product introduction
Throughput	Flexibility	Multi-use machinery
CIM, robotics	Logistics, flow dynamics and design	Design to reduce handling and movement
Long series, undifferentiated products	Short series, specific products	Personalised products
Product, price	Solutions, services	Price premium for quality, reliability, performance
Quality control	Performance audits	Equal priority given to design, production, delivery
Complexity	Organisation	Prevent dis-function, breakdowns
Hierarchy	Autonomy, responsibility	Better solutions because close to problems
Sub-contracting	Partnerships	Spread risks, share gains
Low labour-cost suppliers	Direct investment in key markets	Directly enter new markets
Local, national markets	World markets	Target products, services, markets

Source: Adapted from L'Expansion, 3/16 May, 1990.

Table 2

Management and investment priorities of medium-sized firms in France: 1989

(percentage of surveyed firms rating priority high or very high)

Mangement priorities:	
Human resources	61
Commercial, marketing	54
R&D	54
Management, organisation	46
Production, logistics	41
Finance	33
Investment priorities:	
Acquisitions, joint ventures, equity participations	65
R&D	55
Production	52
Commercial, market networks	49
Publicity, communications	40
Feasibility studies, design studies, market research	39
Software	37

Source: Adapted from France 300, Bain & Co.

Table 3

Type of manufacturing equipment used: U.K. process users by industry 1987-89

(percent of sample establishments)

	CAD work stations	CNC machine tools	Programmable logic controllers	Pick and place machines	Robots
Food and drink	17	2	68	10	6
Textiles	22	3	41	3	2
Clothing	20	11	32	1	1
Paper and printing	19	5	46	4	2
Chemicals and metals	31	15	72	9	4
Metal goods	17	38	49	21	7
Mechanical engineering	41	63	24	9	16
Electrical engineering	52	41	41	23	9
Vehicles	58	62	41	23	28
Other	19	20	43	13	4
Total 1987	31	28	46	12	8
Expected 1989	46	32	50	21	15

Source: Northcott, J. and Walling, A., The Impact of Microelectronics: Diffusion, Benefits and Problems in British Industry, Policy Studies Institute, London, 1988.

Table 4
Use of selected manufacturing technology by industry: 1989 : Canada
(establishment weighted percentages estimated for all manufacturing plants)

	CAD/CAE	NC/ CNCMT	FMS/ FMC	Pick and place robots	Storage, retrieval	Final inspection, testing	Factory LAN
Food, beverages, tobacco	14	7	11	3	5	12	11
Leather, textiles, clothing	10	14	6	3	4	3	6
Wood	13	7	9	3	4	10	8
Furniture and fixtures	7	7	4	1	1	5	7
Paper and allied products	27	11	7	7	10	30	22
Printing, publishing and allied	14	12	1	3	6	3	2
Petroleum and chemicals	18	3	6	1	8	8	16
Rubber and plastics	10	8	10	3	6	9	6
Non-metallic mineral products	11	13	12	1	14	12	14
Primary metal	28	20	14	6	4	20	20
Fabricated metal products	21	25	7	1	1	8	13
Machinery	36	35	13	5	3	6	9
Electrical and electronic products	42	18	9	2	1	14	12
Transport equipment	34	19	13	12	9	21	18
Other manufacturing	7	9	5	2	1	7	3
All manufacturing:							
Establishment weighted	17	14	7	3	4	8	9
Shipment weighted	49	30	21	15	15	35	37

Source: Selected from : Survey of manufacturing technologies, Statistics Canada, September 1989.

Table 5
Installed industrial robots: stock in selected countries

	Number of robots						
	1980	1983	1984	1985	1986	1987	1988
Australia			528		800	925	1 200
Austria		80	115	170	250	305	446
Belgium	58	514	775	975	1 035	1 117	1 231
Canada	250	700					
Denmark	38	76	114	164	210	287	349
Finland	20	109	180	247	336	424	545
France	580	1 920	2 750	4 150	5 270	6 577	8 026
Germany	1 255	4 800	6 600	8 800	12 400	14 900	17 700
Italy	353	1 510	2 600	4 000	5 000	6 600	8 300
Japan	9 660(1)	29 100	45 000	65 000	82 500	101 000	129 000
Netherlands	51	120	213	350	630	747	845
New Zealand			14	31	42	65	n.a.
Norway	170	200	250	323	396	431	524
Spain	56	433	525	688	895	1 149	1 382
Sweden	990	1 452	1 745	2 046	2 383	2 750	3 042
Switzerland	50	110	191	290	382	450	783
United Kingdom	371	1 753	2 623	3 208	3 683	4 303	5 034
United States	4 500(1)	8 000	13 000	20 000	25 000	29 000	32 600
Brazil				35			
Korea		35	95	249	454		
Singapore	1	70	90	145	227	309	
Taiwan			148	227	292	457	682

(1) Estimates

Source: OECD. Excluding manual manipulators and fixed-sequence robots. End-year values. Original sources were: for 1980: compilation by Japan Industrial Robot Association; 1983-88: compilations by Association Française de Robotique Industrielle and the International Federation of Robotics. Brazil from Edquist, C. and Jacobsson, S., *Flexible Automation*, Basil Blackwell, Oxford, 1988; Korea adapted from Kasuhiko Torii, "Robotization in Korean Industries", mimeo, July 1987; Singapore adapted from Singapore Economic Development Board, August 1988.

Table 6
Stock of industrial robots by selected manufacturing industry: 1988
(percent distribution based either on numbers of robots or their values)

	Metals	Metal products	Machinery	Electrical/ electronic	Auto	Aerospace/ other	Plastics, rubber	Other	Total
Belgium		17		2	61		3	16	100
Finland (1987)		45	14	14	11		4	11	100
France	3	n.a.(1)	23	11	36	2	16	9	100
Germany (1981)		8	15	18	59				100
Italy (2)	n.a.	4	17	9	52	5	4	9	100
Japan	1	3	15	33	27	0.3	15	5	100
Japan (3)	3	5	8	42	27	1	9	4	100
Norway	10	48	13	12	-	6	2	9	100
Spain		28		4	59	3	0.4	6	100
Sweden		16	33	8	29			15	100
Switzerland		6	20	13	4		6	51(4)	100
UK	1	10	7	11	31	3	20	18	100
US (1980)	21	15	7	20	20	7	1		100

1. Not available.
2. Values estimated from 1985-1988 domestic consumption.
3. Values estimated from 1978-1985 domestic shipments.
4. Excluding unspecified. Largest user is food/beverages.

Source: OECD. See Table 5. Excluding robots used in energy, research and education applications. Numerical data for Japan include some simpler robots excluded from Table 5. Data for Germany and Sweden only for metal and machinery industries.

4. CIM TECHNOLOGIES

Computer-Aided Design Technologies

by

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COMPUTER-AIDED DFSIGN TECHNOLOGIES

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Sofia, Bulgaria

The evolution of the concept of the CAD systems was a result of the development of the computing technologies, the automated design methods, instrumental software.

On the first stage separate design operations were automated, more seldom procedures, and as a rule the means created worked in a batch mode, particular methods were automated, which did not influence significantly the designers' labour productivity and the project realization terms. In this aspect, the Institute of civil engineering cybernetics, Sofia; CHIMPROEKT, Sofia and others were in the leading position.

The second stage is characterized with the implementation of the subsystem design method on the basis of universal computers and the coming forward specialized complexes. The design tools are software systems and application programmes, that automate, after linking (generation) to the conditions of the particular object the design process elements (group of design procedures, stages) in given aspects (geometrical, technological, accounting etc.). The effectivity of the design automation means on this stage did not differ essentially from the previous, in connection with locality and sometimes in the casuality of the choice of the automation object and the limited capabilities of the computing means. The organizations, that have made a significant progress in this stage are the Computing Centre at the Shipbuilding Institute - Varna, MASHPROEKT - Sofia, etc.

The third stage is characterized with a significantly more complex approach to the automation, than the previous ones. The procedures, realized earlier as local, were now linked functionally and informationally between each other. Based on a uniform data basis, procedures relating to different aspects of the design object description were automated. On this stage the creation of a sufficiently complete information model of the object could be mentioned, used for different applications automation. The degree of routine operations automation (drafting, product specification, etc.) was high, as well as of various operations requiring labour-consuming computing (strength calculations). A significant local effect is obtained out of the implementation of such systems, but it insufficiently influences the common features of the design process. In this aspect the experience of ZIENO at the Combine for radioelectronic devices - Veliko Tarnovo, ZZU - Plovdiv and others is successful.

The fourth stage is the stage of the complex design automation. It allows for the sudden raise of the designers' labor productivity and the decrease of the terms of process planning. The main factor for achievement of effectivity is the implementation of principally new automated design technologies, based on total computerization of the working places, significant intensification of the information exchange, wide utilization of the methods of computing experiments, means with elements of artificial intellect.

In this way, from the point view of effectivity, the first three stages of the CAD systems evolution, shoud be considered as preparatory, allowing to accumulate the necessary scientific, methodological, technical, qualification and realization potential.

When analyzing the contemporary level of the system development in leading west companies, as well as our experience, it is necessary to mention the following: the implementation of systems, corresponding to stage 3 is maintained industrially. The price of such systems is relatively low. Systems, corresponding to stage 4 in their features, exist and function.

The level of the development of the design automation means in the country corresponds to the second stage of the CAD systems evolution and there are some features of the third. A significant delay in the development of the computing technology means detains the transition to the third stage.

Each stage of the CAD systems evolution has corresponding technology and technological environment.

The life cycle of the devices represents a cyclic interlinked process of accumulation and specification of knowledge and its realization in design, production and exploitation.

The basis both of the conventional and the automated technological cycle of realization is the description of the object in models of different types.

The analysis of the vital cycle of the product provides grounds to examine the design and production processes as a uniform process. The objects "processed" during this production are informational and material.

The certain reserve in the adoption of a unified viewpoint is explained with the insufficient appreciation of the fact, that the material production is the only continuation of the information production and the level of development of the latter defines the common level in the development of the production as a whole.

This insufficient appreciation torpedoes the whole process of automation in general.

Having in mind, that the product on the stages of "pure" design is a complete "ideal" model of the article and its production, a conclusion may be drawn, that on the design stages a production information model (PIM) is created, that in turn is an information environment of the material production process.

The basis of the production information model is a complex of interlinked models: production object, production process and process planning.

Every production, including information, is characterized by three components: technology, organization and tools. Each of them is in dynamic interrelation with the rest, but the determining is first of all the technology, being the product of the complex view on the production problems, as a result of special scientific investigations in a particular field of knowledge.

The significant, for the time being, delay in the field of product design under new technology is connected, first of all, with the absence or slow development in the field of creation of principally new technologies in the information production, without which even the most contemporary tools, that are the CAD systems are ineffective. It turns out in the unsystematic mechanic saturation of the branches with design automation means, that does not lead to qualitative results if this tool is not chosen after a particular technology, corresponding to the level of the tool development. This is a typical picture for almost all of the East-European countries members of the Council for Economic Mutual Assistance. In other words it should conform to the requirements of the scientific and technical uniformity and technology balancing. It so happens, that in the material production sphere, when a technological line is outdated, the contemporary equipment determines reformation or its complete rejection.

The development of the design technology has two stages: stage of conventional technology development, and stage of design technology automation. The first of the above-mentioned stages comprises the manual and mechanic technology, regardless of the fact, that the instrument maintaining this stages is not able to lead to some essential changes in the design process and to raise significantly the labour productivity.

It is known, that the development and realization of the huge complex projects in an arbitrary technology field requires investment of significant means, both material and instrumental, effective coordination in the work of the co-executors, prospective orientation. This could be seen in the experience of the other countries, where the basic executors of the prospective approaches are large companies with personnel of ten thousands. On the other hand our experience shows, to a certain extend, the misunderstanding of the importance and difficulty of the complex solution of the question of the software provision, closely linked with the questions of the automated design methodology.

One of the main questions in the creation of complex systems for automated design is the development of standards in the CAD systems. The development of these standards allows for the solution of the problem of the different subsystems information compatibility. The general purpose of the standardization in the CAD systems may be formulated as achievement of the structural, informational and technological unity of the development.

On the first level the necessity in standardization is expressed in the use of the information received on the first stages of design in each of the following. Besides this, the necessity of creation of mutual data basis and the ensurance of its application tasks independance may be performed only on account of the standardization of the data transfer form.

According to the data of some investigations, the raise of the labour productivity in 1990 in the sphere of design will grow 5 times, and at the same time the labour productivity in the material production sphere has raised 1000 times.

As the raise of the labour productivity is connected only to a certain extend with the intensification, more radical ways are necessary, connected with significant increase of the capital investments. In the design field, in its initial stage, the expenses for tools, now include an insignificant share of the expenses in the general structure.

Characteristic features on the automation stage appear to be the drastic increase of the capital investments in the information production sphere, on account of the implemented computer technics and software.

On this stage a basic determining element, as well as in the previous stages, are the means of the natural intellect; but in the process of development of the methods for information formalization and their processing procedures by the means of artificial intellect they will take the first place according to their volume and the level of solved tasks. In this way the tendences of transition from the automation stage to the stage of automatic technologies is connected with the artificial intelligence development, automated storage and access to the information funds.

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On the second level the transition of the CAD system to the technological environment of the specialized complexes is provided, and the conceptual unity with the possibilities of complex generalization is guaranted. For this purpose a standard should be developed.

On the third level of standardization the necessity of the unification of the inner storage form and the transfer of images or formats of metafiles in virtual device arise. The development of the graphical kernel standards and metafile formats allow for the achievement of the required independence of the outer devices.

All mentioned above is an opinion of very serious and respected individuals, but the future, that will be much more different from all that we imagine now, will show how far from the truth we were.

Analysis of the results of investigation held on the IX and the X International seminar 'CAD/CAM - Next Step' and information received from 25 implemented systems for the period 1988-1990

1. Objectives of the investigation

The objective of the present investigation is to identify the problems, that accompany the CAD systems development and implementation in Bulgaria. The idea is to lay the foundations of information accumulation and systematization on separate groups of problems, that is aimed to assist the decision-making in the corresponding field in the overcoming and the existing problems and timely identification of the potential problems in the development and implementation of CAD/CAM systems. As far as we are informed, for the time being, investigations with similar objectives were not carried out.

2. Generalized conclusions

As a result of the analysis the following generalized conclisions may be derived:

(a) Basic groups of CAD/CAM users:

* Design organizations	- 36/24 %
* Higher Institutes	- 20/24 %
* State organizations, combines and enterprises from different industry branches (mechanical engineering, electrotechnical and electronic industry)	- 44/52%

The relatively weak presentation and/or lack of interest of one category potential CAD/CAM users make imperesion, namely the enterprises of general mechanical engineering in 1988 and the weak positive tendency in 1990.

(b) The outputs pursued by the CAD/CAM implementation.

The wandering in the answers of this question is considerably lower compared to the previous one. Depending on the frequency of the mentioning of the answers, they are as follows: shortening of the design cycle (acceleration of new products implementation) 15/15 % ; increase of designers'/ constructors' productivity 30/30 % ; constructions optimization (possibility to carry out analisis) 15/15 %; quality increase 10/10 % ; drafting activity automation 25/25 % ; reducing of the production expenses 5/5 %.

(c) Critical for the success factors

The wandering in the answers of this question is also high, but they may be generalized in the following groups:

- manpower
- the available hardware and software (including lack of information on what is offered)
- economic factors: lack of financial means
- lack of systematic approach in implementation
- appropriate organizational environment

(d) Is there a long-term plan for the implementation of CAD/CAM systems, able to provide for the accomplishement of the economic purposes of your organization?

The answer of 60/52 % of the participants in this investigation is negative.

(e) Who is the initiator of the system development?

The answers may be generalized in the following three groups:

- 'from above'
  centralized from the higher organization (state enterprise, combine, institute, or specialized section/department in the corresponding organization
- from the CAD/CAM system designers
- 'from below'
  from separate users - enthusiasts

(f) Are there established procedures/methodology for the system development?

The answer of 85/72 % of the participants is negative.

(g) The basic conclusions regarding the detaining factors for CAD/CAM systems development and implementation. The answers corresonding to the frequency of their mentioning follow:

* available resources: lack of specialists lack of appropriate organizational environment lack of technology	- 70/83 %
* restrictions on behalf of the existing systems	- 10/7 %
* indeterminateness and dynamics of the technology development	- 20/10 %

(h) When will appear real prerequisites for the realization of computer-integrated manufacturing systems in Bulgaria?

Tha answers vary between 1995 and 2000 depending on the readiness of the users, economic stimulus, the presence of adequately trained personnel and successful passing from the obligatory transition stages.

(i) What are the difficulties of organizational-management character you encounter in the implementation of CAD/CAM systems in your organization?

- 'resistance' to alteration on behalf of the users
- training and re-qualification
- structural changes in the organization
- lack of economic interest on behalf of the users

(j) What are the possible means for solving of the above-mentioned problems?

- education and training of the users
- participation of the users in the development of the systems (joint approach)
- alterations in the organizational structure
- use of outer organizations as consultants
- pilot developments
- government strategy in the field of CAD/CAM

The order of the answers of the last two questions corresponds to the significance that is alloted by the participants to the potential problems and the possible means for their solution.

Flexible Manufacturing Systems: The Technology Behind the Success

by

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FLEXIBLE MANUFACTURING SYSTEMS: THE TECHNOLOGY BEHIND THE SUCCESS

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1. INTRODUCTION

The paper presented here is an attempt to provide some answers to basic questions which are raised at the start of a CIM-project.

> How much does productivity grow?
> What causes this productivity improvement?
>
> What is the impact on production capacity?
>
> Why flexible automation is flexible?
> When flexible automation is flexible?
> How flexible is a FM-system?
>
> What is the impact on quality?

Some of these questions are the correct questions to ask and there should be answers to them. Some of them are of interest only from an academic point of view. For a production company there might be much more important questions related to investment justification, such as:

> Will we be able to enter new markets with the latest production technology?
> Are we ahead of competitors in production technology?
> Do we have enough strategic flexibility in a dynamic market position, or are we fixed to comparatively rigid system structure?

1.1 About the data

The IIASA CIM-project was carried out to examine in some depth how FMS-implementations have been realized and what have been the major objects and results of the investments. The questionnaire contained more than 200 questions and these were completed during direct interviews with production managers or managers at corresponding levels with responsibilities over production. Questions were divided into technical, economic, organizational and managerial issues. Altogether forty cases from Austria, Czechoslovakia, Bulgaria, Finland, GDR, Sweden and Taiwan were fed into questionnaire data bank. Two cases from the UK were also provided by a national collaborator. Cases have been analyzed from different perspectives by Maly, Mieskonen and Tondl. (Maly 1990, Mieskonen 1989, Tondl 1990)

The Finnish TES-programme[1] collected additional data about production flexibility in FM-systems and about the major reasons for investment in flexible automation. The results of the programme have been included in numerous reports in Finnish by SITRA[2]. A concluding summary in English will be part of volume IV of the IIASA CIM end report series.

2. MAJOR DRIVING FORCES IN THE USE OF FM-SYSTEMS

According to our questionnaire data the following reasons (table 1), were found to be most important in justifying FMS investment. Most of the reasons are directly or indirectly related to productivity or production flexibility. The long term need for production capacity was also frequently mentioned during interviews.

TABLE 1 The main reasons for FMS investment.*)

- decrease of	-production cost	(P)
	-labour force	(P)
	-capital tied to inventories	(P)
	-delivery time	(F)
- increase of	-delivery service	(F,Q)
	-profit margin	(O)
	-flexibility	(F)
- to be pilot investment		(O)

*) Source: IIASA FMS questionnaire. Abbreviations: F for flexibility, P for productivity, Q for quality and O for other reasons.

Quality does not seem to be directly important among the reasons for FMS-investment. - Quality is one necessary feature of modern production and should be at high levels with or without FM-systems. It was not mentioned in any of the answers to the short questionnaire (in Finland), and in the IIASA-questionnaire, quality was only in a middle-order ranking of reasons for FMS-investment.

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[1] Scheduled to last three years, the Finnish national TES-programme started in 1987 to support IIASA's TES-programme and to carry through a national study of structural change in manufacturing industries in Finland.

[2] Finnish National Fund for Research and Development

3. PRODUCTIVITY INCREASE

The most obvious (traditional) reason for automation investment is to increase productivity. In our cases, productivity has increased roughly 200 per cent on average and the standard deviation is approximately 100 which shows that the cases are quite different. Increased productivity is a combination of the reduction in numbers of the labour force, a decrease of capital embodied and an increase of production volume.

3.1 Labour productivity

Figure 1 below shows the individual Austrian, Czechoslovak, Finnish and Swedish cases in personnel reduction and productivity improvements. A curve of stars shows productivity growth which would be achieved if productivity growth is caused only by personnel reduction. The cases above the line indicate productivity increase which is due to technological development, capacity increase etc. The cases exactly on the line indicate instances where productivity increase figures have been calculated directly from labour savings - so other reasons for improved productivity have been omitted. Partly this can be because of an inadequate understanding of the questionnaires with regard to productivity or the interpretation of productivity caused by labour productivity only, on the part of the respondents.

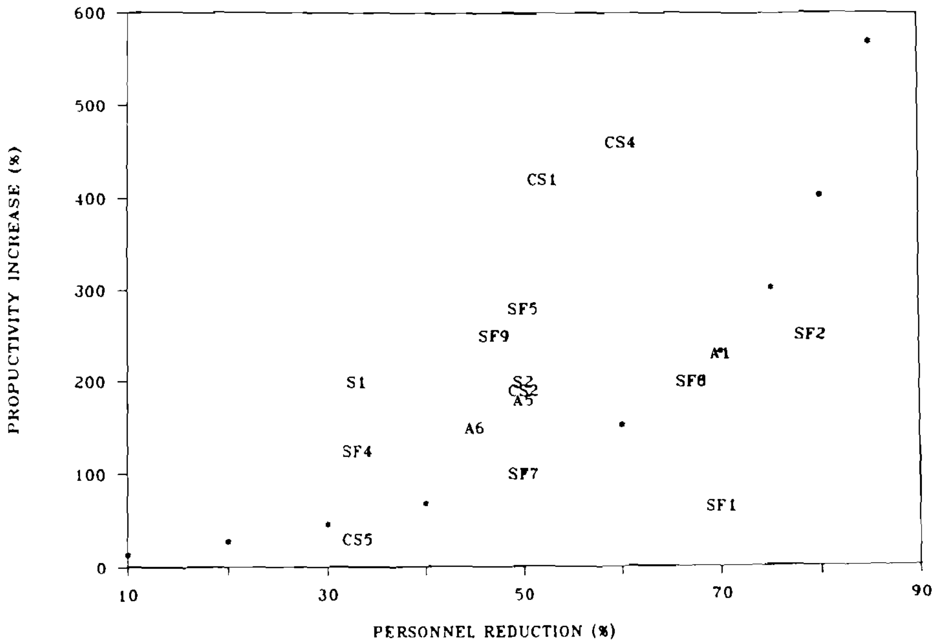

FIGURE 1 Personnel reduction and productivity increases in seventeen cases from questionnaire data.

Another main driving force for personnel reduction is lack of qualified labour in certain industrial sectors. An insufficient labour force makes automation more credible, particularly when the company is in an expanding mode. In such a case the problem is rather in increasing production capacity with the same level of labour, instead of reducing manning levels, as was clearly visible in the case of Austria, Finland and Sweden. Partly because of age structure, partly because of the unattractiveness of the industry among the young generation of workers, the metalproduct industry is desperate for labour in order to keep up expansion when demand for products is high in these countries.

The lack of qualified labour does not mean that production will be managed with less qualified labour in the future. Instead it means that operators will have broader skills but in relation to production levels there will be less direct labour employed.

3.2 Capital productivity

Capital productivity can be viewed from two main sides; capital embodied in machines and capital embodied in inventories in the logistic chain.

Capital embodied in machines is a two sided question in CIM-investment. On the one hand, when investing in flexible automated production facilities the number of machines needed for the same output is decreased. Our questionnaire data shows that the average relative reduction in the number of machines is about 60%. Using absolute numbers it means more than 10 machines are removed per system. Partly this is a result of the use of machining centers (M-C's) instead of drilling, milling and boring machines. In some cases M-C's are also used to replace turning machines.

On the other hand machines used for automated functions tend to be more expensive than conventional stand alone machines. Additional investments are also needed for integrating individual machines to form a system (material handling, internal transportation, tool management), process control for controlling and monitoring performance of the system and single devices (computers, PLC's) and data transmission (LAN, MAP, optical fibers).

Using traditional approaches capital is usually substituting for labour. After these 'additional' expenses it is questionable if the use of fewer machines has led to less need of investment. Contrasting evidence has emerged from our questionnaire study. Some cases show a real decrease of capital needed for machines while others show some increase. This is partly a consequence of how the company using FM-technology considers the value of old machinery. Old equipment could already be written off and awaiting replacement by new equipment. On the other hand they could still be perfectly useable for the operations they were designed for. When the situation is the replacement of already aged equipment, FM-system is compared to other alternatives. When investment for FM-technology is considered mainly according to strategic benefits, the question is how to consider old machinery; as a sunk cost or still active part of capital embodied in machinery.

Although the capital needed for investment is important, very seldom have the companies in our data considered lack of capital to be the main obstacle to investment. In appendix both barriers to and factors accelerating FMS-investment are shown. Lack of capital was not mentioned as a crucial factor. This does not mean that there is too much free capital for investment, rather it shows that production investment is made if it has solid justification.

The aim of reducing inventories is certainly one of the major reasons for FMS adoption. Cases in both Austria and Finland particularly emphasized this. In Finland stocks were reduced by roughly 80% on average and WIP by 75%. Austrian cases showed concern for inventories, although the decrease was modest 25% and roughly a 40% reduction in WIP. Although less emphasis was given to stock reduction in Sweden the figures were roughly the same as in Finland. In Czechoslovakia inventories increased slightly due to FMS implementation. This could indicate a pure match of company's overall strategy and the technology in use.

3.3 Prerequisites for productivity development

Total Preventive Maintenance concept (TPM) is an essential aid to guarantee productivity increases when using complex system technology. Without stable production output and error free operations inventories cannot be cut efficiently. Unmanned operations or operation with reduced manning levels is not possible if the performance of the system is not strictly under control.

The availability of the system depends on every system component plus some external factors such as: quality of electric power, quality of raw materials. If the availability is not high enough (between 95 - 100 %) it is very difficult to reach the aimed for productivity improvements. (Mieskonen 1989, Simons 1990)

High availability is in turn a necessity for high utilization rates which in turn guarantees high productivity. There are different approaches for considering utilization rate; The 'Japanese way' is to use machinery with lower speeds during unmanned shifts and shifts with reduced manning levels, and to reserve enough time for preventive maintenance (Schonberger 1986). The here aim is to ensure stable production. Some Western cases show a desire to consistently load machinery all the time to its limits. This results in high utilization for short periods of time but rapid wear of critical machinery because of lack of time for preventive maintenance. (Lakso 1988)

High utilization should not be one eye target. We should remember that utilization rate is one way to quarantee high productivity, but it should not be an aim in a cost of long term availability.

With utilization rates we should be careful not to minimize our capacity flexibility by loading the system to its limits all the time. Also we should keep the JIT principles in mind and not keep systems running when demand pull from assembly is absent.

In most cases, an increase of operational volume is the best situation for productivity increases. In many cases, companies still employ people who were cut from direct production functions as a consequence of FMS installation, but who now work in different departments.

4. CAPACITY INCREASE

Capacity increases have an indirect connection to productivity issues. In some cases the need to increase production capacity has clearly been the main driving force for the initial investment. In some of our cases after taking account of all restrictions (labour availability, space limits etc.) compact system technology with higher automation level has emerged as the most feasible concept.

It is difficult to exactly show the increase of production capacity using our questionnaire data, because most of the FM-systems produce slightly different set of parts than before FMS installation, or the system is part of a brand new factory without real time series of capacity. Although most of the production managers interviewed explicitly regarded a capacity increase to be one major driving force.

Conversely, capacity increases can in part be unintended. In particular, small companies overestimate their marketing power when taking on board the latest technology. The success of automation investment is heavily dependant on the availability and utilization of the system. Keeping that in mind the size of a system should be defined very clearly according to real needs, otherwise there is a risk of losing some of the benefits of system technology by keeping expensive capital embodied in unused equipment. Overcapacity will threaten the principals of JIT production if you are trying to keep machines running without demand pull from assembly.

The higher capacity of FM-systems compared to stand alone machines is based on better time efficiency. Basic machining technology is not so different and the tools and tooling technology is quite similar. Sometimes it is necessary to use less efficient but more reliable tools in a system than in manual operations because of the need to keep the system running without direct human control. Time efficiency comes from zero set up times and stored settings. Set up has become a function outside the normal set up time which normally (earlier) meant interrupting machining. Machines are also running through coffee breaks and lunch breaks and sometimes unmanned through night.

5. PRODUCTION FLEXIBILITY

Production flexibility also has a connection to productivity. Flexibility of the production system quarantees high productivity when a large product mix and uncertain demand for different products exists. Although the product mix is large the need for single parts to be produced should be on-going, otherwise it makes no sense to store the hardware and software needed, e.g. NC-programmes, expensive pallets and fixtures for the part.

The essential question with production flexibility is that different companies in different markets need to emphasize different sets of flexibilities. In the short questionnaire survey carried out in Finland, in response to asking which kind of production flexibility was improved when FM-system was taken into operation, it can be seen from fig. 2, FM-technology was considered about one ranking higher overall than conventional production (average for FMS is 3.8, std = 0.45, average for CONV. is 2.71, std = 0.28).

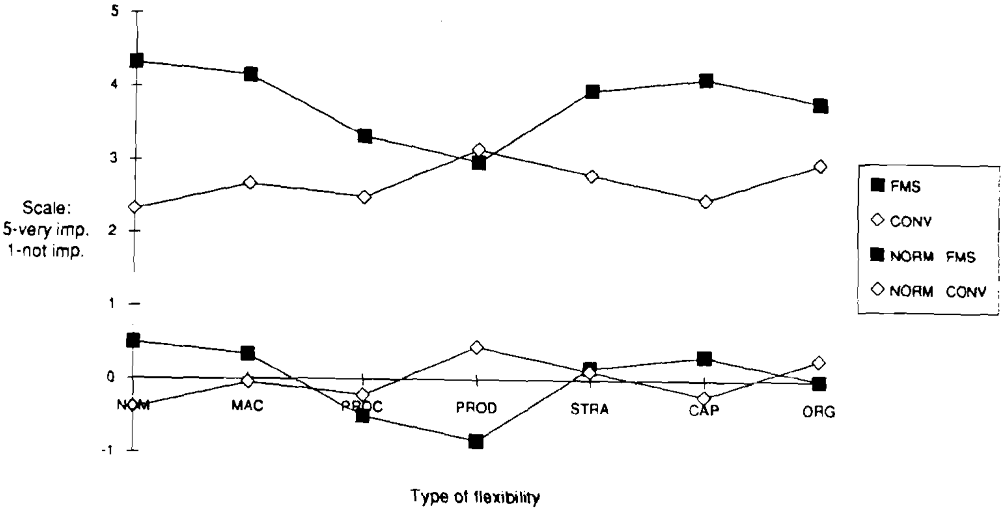

FIGURE 2 Production flexibility supported by FMS and conventional production. *), **)

*) The scale of the answers is 5 - very important, 1 - not important. (Mieskonen 1989).

**) Key for shortening (Mieskonen, Kemppi 1989):

NOM	Nominal flexibility	MAC	Machine flexibility
PROC	Process flexibility	PROD	Product flexibility
STRA	Strategic flexibility	CAP	Capacity flexibility
ORG	Organizational flexibility		

5.1 Technology behind flexibility

It is interesting to find the opposite shape of the curve for FMS- and CONV-production when the curves are normalized at the same point of the Y-axis ref (fig. 2 lower curve). Conventional production seems to support product flexibility (the ability to take new parts into production) better than FM-technology. The interpretation for this could be that the integration between CAD-systems and FM-systems are not yet sufficiently well integrated. Also, the complexity of the fixtures and tools needed for unmanned production decreases product flexibility when using systems technology. It takes a longer time to prepare all the necessary procedures for FMS production than it took in conventional production.

Flexibility of the production system is a result of different components of the system. Critical for nominal flexibility are the number of different tools in the system, multifunctionality of the machines and number and functionality of pallets. The number of tools tends to be critical because it restricts the number of different shapes possible to produce in the system. On the other hand when trying to tackle the problem of too large a number of tools by using multifunctional tools, we end up restricting flexibility while these tools might be dedicated to a few special operations only.

6. QUALITY IN THE BROAD SENSE

Quality improvement has been one hypothesis employed in research done concerning the justification of FM-investment. Our study does not support the theory that FM-systems are adopted primarily to improve quality. Only in Swedish firms did quality issues clearly put strong emphasis on this. In some Finnish cases quality was considered to be important but the attitude was that quality must be high with or without flexible automation.

FM-technology itself does not have specific tools to improve quality levels but it certainly has an influence on keeping quality levels stable. This control over variability of production is the major link between TQC and JIT (Schonberger 1986). Also, indirectly quality could be improved because automated functions need better raw materials and more specific guidelines for production. But that is not actually because of the FM-technology itself but rather that the use of automated functions require better castings, more reliable tools etc..

Even though quality was not explicitly mentioned among the three most important reasons for FMS-investment it is clear that it implicitly influences the investment decision. Particularly when we consider quality in the broader sense. Thus, quality of production includes some characteristics common to flexibility, such as shortened lead times from order to delivery, large product range offered to meet specific needs of customers, and delivery service.

6.1 Imperative for stable quality

Stable quality and control over variability of raw materials are essential preconditions for automated production. These same characters are also aims of flexible automation when looking end product's point of view. Fluent and thin production flow can not afford scrap and there is no room for rework in automated factory.

7. CONCLUSIONS

It is not only FM-technology which causes an impact on production performance, and it can not have a major impact on its own. FM-technology must be considered as a tool to put into practice some general principals coming out of JIT schemes. There are simultaneously several developmental trend, such as:

- JIT production including basic ideas for simplifying production
- TQC, concern about quality improvements at all levels of the company
- Customized products, the customer is king and their needs should be fulfilled
- Zero inventories, the elimination of excess stocks in production
- CIM, overall integration of functions related to production
- Networking activities, to implement value adding chain

Most af those companies which have been actively investing in FM-technology have also been at the leading edge when cell based manufacturing was taken into operation, and stocks of finished parts were being reduced. All of them are experienced with NC-machines in general and most of them had earlier experience of unmanned manufacturing in particular. As listed in the appendix, these same factors are major accelerating factors behind FMS investment.

The technology itself does not solve the production problems. The performance of production depends on how you use the technology which is also available to your competitors.

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APPENDIX

BARRIERS TO, AND FACTORS ACCELERATING THE DIFFUSION OF FM-TECHNOLOGY

The following aspects were raised when factors accelerating and barriers to diffusion of FM-technology were discussed:

The most important reason for accelerating the diffusion of FM-technology is earlier experience of 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.

As can be seen, the problems run from philosophy to the quality of electric power. The pioneers have faced most difficulties from the lack of vendors and unreliable system components. Many of the companies seem to expect too much from the vendors. It was something of a surprise that none of the companies mentioned lack of capital or too high investment costsas a barrier to investment. Also, none of them mentioned unsatisfactory investment calculation methods as a barrier. There seems to be more lack of knowhow than money.

ACCELERATING FACTORS

Technical:
- -knowhow of NC-technology
- -earlier experience of FM-technology
- -earlier experience of unmanned production
- -construction changes in product
- -starting with JIT philosophy

Economic:
- -need to increase profitability
- -need to decrease unit costs

Organizational:
- -lack of skilled workers

Marketing:
- -need to raise capacity
- -investment as a reference

Strategic:
- -strategic decision to invest in system technology

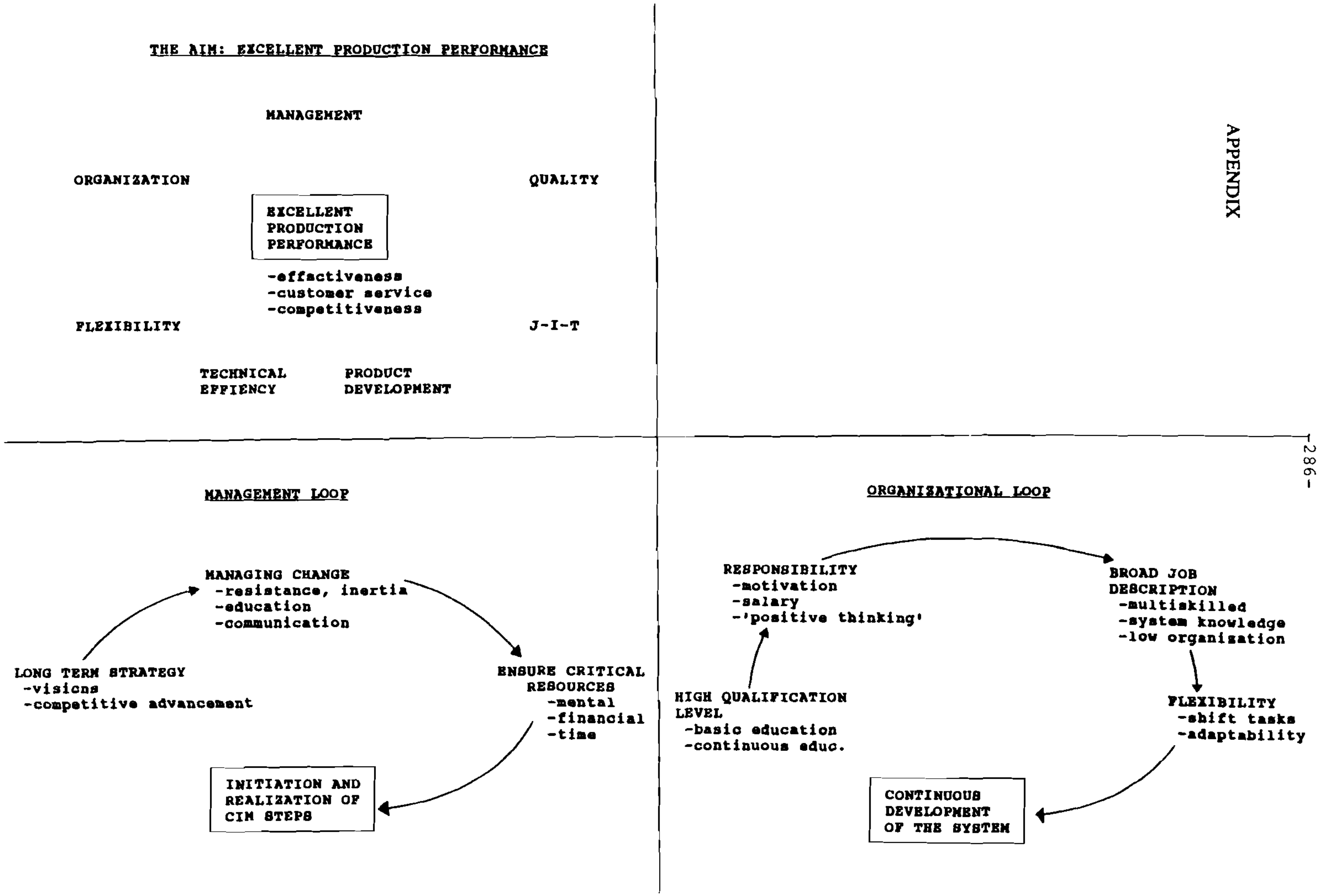
BARRIERS TO DIFFUSION

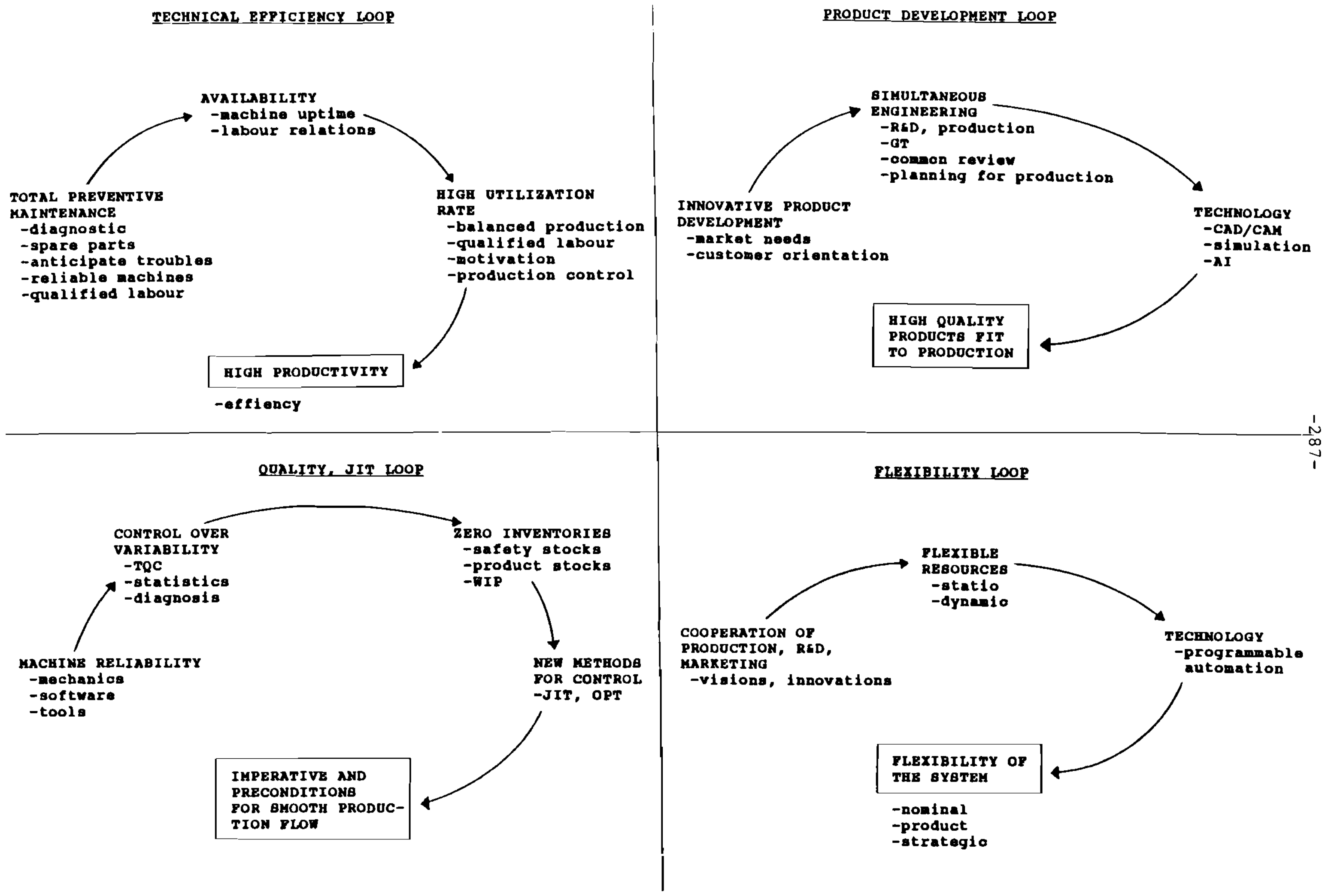
Technical:
- -lack of technical support from vendors
- -lack of CIM-knowledge at every level of the company
- -vendors do not have practical references
- -the old products do not fit automated production
- -components for automation are too unreliable
- -too many different parts for FMS
- -quality of 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

APPENDIX


THE AIM: EXCELLENT PRODUCTION PERFORMANCE
MANAGEMENT
ORGANIZATION
QUALITY
EXCELLENT PRODUCTION PERFORMANCE
-effactiveness
-customer service
-competitiveness
FLEXIBILITY
J-I-T
TECHNICAL EFFIENCY
PRODUCT DEVELOPMENT
MANAGEMENT LOOP
MANAGING CHANGE
-resistance, inertia
-education
-communication
LONG TERM STRATEGY
-visions
-competitive advancement
ENSURE CRITICAL RESOURCES
-mental
-financial
-time
INITIATION AND REALIZATION OF CIM STEPS
ORGANISATIONAL LOOP
RESPONSIBILITY
-motivation
-salary
-'positive thinking'
BROAD JOB DESCRIPTION
-multiskilled
-system knowledge
-low organisation
HIGH QUALIFICATION LEVEL
-basic education
-continuous educ.
FLEXIBILITY
-shift tasks
-adaptability
CONTINUOUS DEVELOPMENT OF THE SYSTEM


TECHNICAL EFFICIENCY LOOP
TOTAL PREVENTIVE MAINTENANCE
-diagnostic
-spare parts
-anticipate troubles
-reliable machines
-qualified labour
AVAILABILITY
-machine uptime
-labour relations
HIGH UTILIZATION RATE
-balanced production
-qualified labour
-motivation
-production control
HIGH PRODUCTIVITY
-effiency
PRODUCT DEVELOPMENT LOOP
INNOVATIVE PRODUCT DEVELOPMENT
-market needs
-customer orientation
SIMULTANEOUS ENGINEERING
-R&D, production
-GT
-common review
-planning for production
TECHNOLOGY
-CAD/CAM
-simulation
-AI
HIGH QUALITY PRODUCTS FIT TO PRODUCTION
QUALITY, JIT LOOP
MACHINE RELIABILITY
-mechanics
-software
-tools
CONTROL OVER VARIABILITY
-TQC
-statistics
-diagnosis
ZERO INVENTORIES
-safety stocks
-product stocks
-WIP
NEW METHODS FOR CONTROL
-JIT, OPT
IMPERATIVE AND PRECONDITIONS FOR SMOOTH PRODUCTION FLOW
FLEXIBILITY LOOP
COOPERATION OF PRODUCTION, R&D, MARKETING
-visions, innovations
FLEXIBLE RESOURCES
-static
-dynamic
TECHNOLOGY
-programmable automation
FLEXIBILITY OF THE SYSTEM
-nominal
-product
-strategic

Hungarian FMS/CIM Developments — Case Study

by

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Hungarian Academy of Sciences
Budapest, Hungary

HUNGARIAN FMS/CIM DEVELOPMENTS - CASE STUDY

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Abstract

This paper gives some details on the evolution of mechanical engineering automation in Hungary. We restrict ourselves to the automation of part production as it seems to be the most complicated and most characteristic of the broad area of all mechanical engineering areas. We shall start with the early CAD/CAM efforts of the sixties, and follow the development of FMS systems in the seventies until recent FMS/CIM implementations in different factories and research/development facilities, including technical universities. It should not be forgotten, that the authors work in a research institute (CAI) which was (and is) involved in most projects.

INTRODUCTION

We wrote Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) programs already in the sixties, when the first real, universal digital computers appeared in Hungary. The first efforts in electronic design were rapidly followed by programs assisting the mechanical engineering design and production. NC/CNC programming and semi-automatic drawing were believed as real CAD/CAM for a long time.

As NC/CNC, PLC and DNC controlled machine tools and robots with RC spread out the idea of Flexible and Integrated Manufacturing Systems (FMS, IMS), and Cells (FMC,IMC) attracted more and more attention. The Computer Integrated Manufacturing (CIM) concept of the early seventies were defined as the need of Integrated Data and Material Management/Processing Systems (IDMMS, IDMPS).

DESIGN AND IMPLEMENTATION OF FLEXIBLE MANUFACTURING SYSTEMS

The concept of integrated data and material processing systems were first studied in Hungary already in 1971 (Nemes, 1971) under the auspices of the State Committee for Technical Development (SCTD).

SCDT was active in supporting experts working on reports and studies dealing with mechanical engineering automation problems, already in the late sixties. These materials were distributed to several factory, university and research experts, however they were publicly not available.

- 1968 : Study on new NC technologies - on-line machine tool control, NC/CNC/DNC, etc.
- 1969 : Study on the development trends in mechanical engineering
- 1970 : Report on the support of research and development and the diffusion of NC technique

As a result of the CIM study in 1971 a three year research project was started and supported. The final result of this project was a set of further reports.

Based on these reports the SCDT invited university, research and industry experts to define the goals of future FMS systems. Then the implementation of five systems were started with considerable SCDT support in the second part of the seventies.

The following section gives short summaries of these systems, emphasizing the common features of them.

1. Computer and Automation Institute & Technical University

A joint experimental workshop - an early pilot plant to make experiments to test CAD/CAM/CAPP/CAQ/CA... program developments

* TPA 11/40 computer; centrally controlled
* Different types of CNC controlled lathes, machining centres and robots

The system was designed and implemented from 1976 to 1980 and finished its job in 1985.

2. CSEPEL Works, Budapest

IGYR 630, a real production system, working as FMS/IMS

* For prismatic parts, up to the size of 630x630x550 mm
* Controlled by two TPA 70 (16 bit) microcomputers as DNC (The second computer is used as reserve and for production planning)
* 6 machine tools with CNC controllers
* Automatic transfer line
  tool exchange
  scheduling
* Manual palette preparation

The system still works in two shifts

3. Machine Tool Works, Budapest

DIAGON 500

* For prismatic parts, up to the size of 500x500x500 mm
* Controlled by an R 10 microcomputer
* 6 cells with cell concept (machine tool+palette-exchanger)
* Automatic multilevel storage
  fixture and tool management

The system has never been completed, but it was de-assembled to parts.

4. Electrical Machine Factory, Budapest

FIG

* Controlled by a TPA 70 microcomputer
* 5 individual CNC controlled machine tools, no DNC control
* No automatic transfer line

Ran out of funds, the project manager was changed three times in two years

5. Machine and Elevator Factory, Budapest

HAFE-800

* For prismatic parts, up to the size of 800x800x600 mm
* Controlled by a TPA 70 computer in DNC mode
  An other similar computer is used for production planning
* 3 CNC controlled machining centres+a measurement station
* Automatic transfer system

Some parts of the system are still working

Evaluation of the experiences with early FMSs

All systems have several common features and common experiences, which are mostly not positive. These are the following:

- they are to produce only prismatic parts
- only Hungarian made machine tools were used
- developments (including design) were mostly independent of each other, except some efforts of common subcontractors (as our institute)
- planning with underestimated costs
  time
  software needs
  necessary computer capacities
  (mostly because of being afraid of loosing support if estimated costs, time, etc. were too big)
- too long implementation times
- lack of experienced factory personnel
- lack of unmanned operation in most cases
- poor system concept in design and implementation, lack of design methodology
- poor or no quality checking and measurement
- low reliability because of
  * using prototypes of home made (Hungarian) equipment
  * interfacing problems
  * personal and personnel problems
  * lack of experience

If we take a look at the above list it is clear, that these projects (perhaps except the IGYR 630) were not really successful. It may be risked to say that they were premature. Based on experiences from the design, implementation and operation of the above systems it became obvious for most experts that the integration of data and material processing systems (CIM concept) requires new design methodologies (see Létray, 1985). One of the reasons is that the development of the system components is definitively faster than the development of the synthesis theory.

The systems were evaluated in details according to the level of automation, integration, and flexibility on one hand and structure, production control, tool-system and material transport on the other hand. (IDMMS Studies, 1985)

In the same time period when the five FMSs were developed some other relevant R&D results appeared in Hungary, as

- A PROWAY-type network was developed to be used in gas, oil, steel, sugar and cement industrial plants.

- PDP-type minicomputers were connected into nets to be used in control and measurement in nuclear power plants.

- Control of discrete parts manufacturing was supported by means of networked high-end PLCs. Plastic industry used the same type of networked PLCs to control extrusion processes.

- A multipurpose, distributed PLC module-system was developed and sold to different countries.

- A special, coax based LAN was designed and implemented to connect all different computers of our institute and to give us a gateway possibility to reach other, remote computer systems. This same kind of office network is used in 8-9 other companies in Hungary, GDR and USSR.

Some weak points of all the above R&D efforts and results (including the FMS implementations) became clear fast enough:

* As the developments were neither coordinated nor any standards were taken into account, the results became not compatible when such demands arose.

* The systems were not upgradable, thus further developments were difficult or even impossible in several cases.

Based on these experiences and on studies of world wide tendencies in establishing FMSs it became clear that short-range and long-range plans should be rather different from each other.

The next table illustrates some of these differences :

Function	Short-range progress	Long-range progress
pre-production activities	technology design (sequence- , operation- , motion-planning)	product design (construction, development, documentation)
Production control	production planning scheduling programming for machining	real-time, adaptive production control (including the entire material and tool flow)
Production	chip-removing manufacturing (including transport)	other activities (assembly, inspection)
New methods and trends		optimization, artificial intelligence

FMS RESEARCH AND DEVELOPMENT IN THE EIGHTIES

From 1982 to 1985 new organizations started to work to coordinate and organize Research&Development. The forces of the Computer and Automation Institute, the Industrial Technology Institute and the Technical Universities in Budapest and Miskolc meant more than 300 highly educated engineers and computer experts being able to do R&D in the field of CIM.

The basis of the next works were studies written as joint efforts to define new CIM concepts. New industrial firms showed up with interest in supporting diffusion of the new technologies as candidates of new FMS implementations.

New, centrally supported projects were started 3-4 years ago to develop new families of controllers of different levels with the direct goal of being open and compatible with the international standards. Such a module system was to be designed which matches the aims of an overall CIM concept (Nemes, Kovács, 1986).

The R&D efforts were supported by purchasing internationally accepted licenses as well to speed up the developments and implementations and to guarantee international compatibility.

Our institute (CAI) is deeply involved in the above R&D projects, and among others we developed a 16-bit industrial cell-controller. The development of the cell-controller was coordinated with all other Hungarian controller developments (PLC, CNC, RoC, etc.). A standard IBM PC was programmed in 'C' to solve all tasks of a manufacturing cell controller. The PC is enhanced by an intelligent coprocessor module card to ensure fast communication with all elements (CNCs) of the cell. Even a production scheduling system belongs to the tasks of the cell-controller (Csurgai,1987 and Bertók,1988).

Two CIM pilot plants to support R&D and industry

Two, government supported CIM pilot plants are under development, which plan to use the most up-to-date MAP, Ethernet and other networking technologies (Haidegger,1987).

One of the main reasons of supporting these pilot plants is to promote industrial FMS/CIM investments by decreasing the recently wide gap between research/development experts and factory engineers. It is a real problem for R&D people to convince the possible users (factory personnel) to apply the available R&D results in industry.

The CAM pilot plant of the Technical University of Budapest (TUB) and the CAD pilot plant of the Computer and Automation Research Institute (CAI) will provide a wide variety of possibilities in the CAD/CAM scene to be used not only by academicians, but by industrial people as well to test their design and production needs and possibilities and to make experiments on different manufacturing strategies. This way engineers and managers can get information on future manufacturing systems not only by designing them, but by making some tests on similar purpose systems.

Both plants should be able to demonstrate all available (Hungarian and foreign) CAD, CAM, etc. programs and technologies to assist industrial people to get the necessary knowledge based on which they will be able to cooperate with R&D (and with foreign trade) people in the design and implementation of up-to-date computerized plants (workshops).

The possibility of checking (simulating/modeling) some main features of future investments seems to be attractive not only for technical people, but for managers as well.

The pilot plant of the Computer and Automation Institute will be a CAD-oriented CIM plant containing 32-bit computers and graphics workstations and a manufacturing cell. The CAD stations and the 16 bit cell-controller are connected by Ethernet network. The manufacturing cell consists of a 5-axes CNC milling-machine, a CNC lathe, a CNC measurement machine and a robot and further elements will be added in the future (Hermann, 1989).

The whole CAD/CAM system of the Technical University of Budapest consists of 32-bit and 16-bit computers in seven different buildings, all are connected by Ethernet. In each building there are one or more LANs connecting the PCs within the buildings. The 32-bit computers run the CAD-programs, and all other machines can be connected via the network to be terminals.

The CAM-oriented CIM subsystem is located in one of the workshops, and it has its own 32-bit host, which is connected to the network of all 16-bit cell-controllers. The LAN of the CAM system is planned to be a MAP 3.0 network, as soon as possible (Cser, 1987). The system will consist of FlexCell based different cells, as a Turning-milling (machining) cell with robots, a Measurement cell with robot, an AGV & Storage cell, a Welding cell and an Assembly cell. A CAD station and a PPS cell will be connected by Ethernet to the system.

EXPERIMENTS ON THE PILOT PLANTS

The hardware-software possibilities of the two pilot plants (including the CAD/CAM/.. programs, networks and mechanical engineering equipment) make it possible to use them according to prescribed design/production conditions.

The given conditions can meet the requirements of planned, future FMS (CIM) implementations, giving the possibility of test-runs and simulation/modeling (Kovács,1990).

Problems of organization and hierarchy

If we suppose a four level hierarchical FMS organization (CNC machine tool, cell, plant/workshop, factory) one has to decide some questions, which may be verified by experiments:

- On which level of the hierarchy should the production planning/process planning (scheduling) be done ?
- On which level (and how) re-scheduling should be processed in the case of any kind of erroneous operation of any element of the system on any of the hierarchical levels ?
- Should the production planning be on-line or off-line?
- On which level (and how) intervention should be done if necessary ?

The correct answers to these and other similar kind of (feed-back) questions assist mostly in proper design of organization of CAD/CAM programming and in evaluating the structure of the planned systems.

Production planning and manufacturing problems

The greatest part of our future experiments deals with finding optimal (or acceptable) solutions of manufacturing according to given tasks.

There are several studies in literature (e.g. Browne,1984, Bonfioli,1985 and Bakker,1988) which give (experimental) data on batch/lot size, flexibility, productivity, number of different products, production volume, necessary man-power, etc. In most cases increasing flexibility decreases the production volume and vice-versa. The decision of using traditional job shop, special automated systems or flexible manufacturing cells/systems, or some combination of them is really crucial.

Generally an FMS producing 100-1000 different products is regarded as an advanced one. This number and all the above data are different according to Western European, USA or Japanese experiences. As we do not have reliable data from the Eastern European countries we plan to use real production tasks to get them. These tests will be the tests of the available software means as well.

As process/production planning is of great importance schedulers of different levels will be tested according to - partly contradictory - criteria, as e.g :

- To minimize the number of products waiting for operation
- To maximize the throughput of the system
- To minimize the average time that products spend in the system
- To achieve JIT operations
- To minimize idle times
- To generate average load on machining resources

Generally no real optimum can be achieved, but one has to manage with good, acceptable solutions as computing capacity and hardware resources are both restricted.

Flexibility studies

The flexibility and the effects of flexibility on other properties of a system/ system components can be examined by means of experiments, too.

The way of getting flexibility, and the methods of measuring the level of flexibility is known from earlier studies (e.g. Browne,1984).

We intend to deal with the flexibility of the following, which has a strong correspondence to each other :

- machine
- routing
- product
- process
- operation
- volume
- expansion
- production

Some of the relationships of these flexibilities will give us good ideas on how to implement and how to run a future FMS.

Simulation and design experiments

The two pilot plants will serve as a background to investigate the above mentioned manufacturing strategies and concepts and on the other hand they will support the simulation, design and implementation of new FMS investments by knowing the similarities and differences and their influences.

RECENT INDUSTRIAL FMS DEVELOPMENTS

As industry become interested in application of computerized technologies again, some FMS developments started in the late eighties. These systems already took advantage of the R&D results of the previous years and of the experiences gained using the pilot plants. Industrial FMS applications got government support as well. In the following only the main elements of some systems will be given:

1. IKARUS Bus Factory, Budapest

* CAD/CAM system for producing bus-body elements, which are complicated 3D parts
* Tool design and manufacturing using 3 pieces of 5D CNC machining centres, a coordinate measurement machine
* CAD/CAM work-stations with the MEDUSA (GB-USA) and the FFS (H) drawing and 3D design systems and with FEM system.

2. CSEPEL Works, Budapest

* MK 500 5D machining centre with SIEMENS controllers and cell controller
* CAD/CAM system, automatic material handling, CAPP system

3. Machine Tool Works, Budapest

* MK 500 5D machining centre with Hungarian cell controller (FlexCell) working in DNC, connected to diagnostics functions
* Ethernet link with CAD/CAM station
* Off-line measurement machine

4. DIGÉP, Diósgyőr

* Sheet metal design and production
* CAD, CAM and CAPP integration
* Automatic transfer lines

5. VIDEOTON, Székesfehérvár

* Rotational parts production
* CAD/CAM/CAPP systems are integrated
* Automatic material and tool handling

- There are some further factories and firms, which are not implementing complete systems, but only system components.

As all these implementations are still unfinished we cannot yet speak about too much conclusions, however the most important ones are clear already and they will be mentioned in the Conclusion.

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 (Létray,1985) should be applied. The working manufacturing systems have proven that the 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 cooperation between different countries in R&D and in implementing systems is impossible without respecting all international standards and prescriptions. The two CIM pilot plants, which are recently implemented in Hungary are serving the above goals, by giving companies a chance to use up-to-date software/hardware means and by assisting education on the graduate, post-graduate and factory level as well. The internationally accepted MAP/TOP standards are planned for application.

One of the basic applications of the pilot systems will be the test runs to get information on the behaviour of such systems when driven by various manufacturing strategies.

Some common features of the recently implemented Hungarian industrial FMSs already show real steps towards the internationally accepted and wished CIM concept as :

- Usage of compatible, interfaceable hardware and software modules,
- Not only the production and its preparation (CAM, CAPP, etc.) are computerized, but the design (CAD) and quality control (CAQ) are integrated into the systems, too

- Even integration of the FMS within the factory was a main issue in all cases.

Finally it is worth while to mention that as there is no automobile industry in Hungary the machine tool factories were the most active in the early and in the recent FMS developments as well.

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Manufacturing Systems

by

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MANUFACTURING SYSTEMS

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In the previous decade automation involved only several isolated activities in engineering production that had to be linked by means of non-automated activities. This "linking up" was rather a difficult task mainly in the area of data aquisition. The current decade, on the other hand, has seen an onset of automation of aggregated activities. Conditions have been provided for a integrated automation of manufacturing processes. Transition toward integrated automation needs the effort aimed at diminishing differences in the level of automation typical of individual technologies, devices, tools, differencies in various degrees of automation in management and control.

Results af many analysis show that manufacturing systems are witnessing dramatic developments. This is a result of a number of factors, of which integrated automation, modularity and integration of manufacturing processes are most significant. Proces integration is understood as a desirable linking of functions and activities. The higher the level of automation of manufacturing processes, the closer the relations and links between individual components and activities, the higner the degree of integration.

Integration of modular type that would meet the newly emerging specific conditions in a flexible way is a powerful tool by means of which manufacturing processes can be improved without changes to the existing enviroment.

Efforts should be aimed at tailored integration, not at an integration at all costs. The degree of integration should be related to the degree of automation and flexibility, and certain optimum must be determined. To achieve the optimum, criteria must first be defined. Various factors may be applied to the choice of these criteria. Two are of utmost importance - economic effectivness and humanization of work. Other criteria, of course, should also be adhered to, such as ecological criteria, quality, lead times, reduced work-in-process, etc. Relations between creative activities and automation must always be considered also. Man is capable of thinking up ideas, but may not as fast as an automated device when comes to the actual implementation of the idea. The automated device on the other hand can produce better results under the conditions that can be achieved by way of algorithms and not as an outcome of creative thinking. Optimal relations will have to be identified between the degree of integration and flexibility. Any improvements in flexibility may result in higher manufacturing costs because machines and equipment will have to be provided with functions that will be only partly used. It has also become apparent that flexible organisational structures will have to become an integral part of future development of manufacturing systems.

APPROACHES TO FLEXIBLE AUTOMATION

Our current knowledge and practical experience can be summed up as follows: The higher the level of automation, the closer the relation-ship between the manufacturing system, the control and management system and the social needs of employees. At the same time the quality and integration of these relations are enhanced.

In this context some findings that have influenced the above mentioned basic concept are summed up:

- the automation of manufacturing processes is not geared to the actual replacement of man by an automated machine or robot. Qualitatively new manufacturing technologies are gradually being developed, among which a substatial proportion of production functions of man are distributed. Their internal structure and mutual relations are different from the current manufacturing technologies.

- the automation of manufacturing processes does not proceed evenly. Workshops with different levels of automation, must however collaborate in a harmonious way. A uniform organization of manufacturing and management and control processes is an integrating factor here, while a modular integration of components is the basic tool.
- the high level of integration of automated workshops in effect means that the work of a team of workers becomes more important than the work of an individual. A comparatively independent set of technological means is controlled by a group of workers, who attempt to produce the range of products required by the plan.
- the importance of such a team-approach is reflected in the organization of work and in the renumeration system. This is not to say that work is more intense but rather that every worker must do what he/she is supposed to do at the right time and to the required standard so that the manufacturing system operates optimally.
- ultimate results are to a large extent decided at pre-manufacturing stages. Workers supervise the actual operation of the manufacturing system and see to it that it is ke, in a troublefree state.
- new demands are placed on the reliability of manufacturing systems. Reliability is not a matter of technology only. Reliability of manufacturing systems depends on a very complex interaction between technological, organizational and human factors.

MANUFACTURING SYSTEMS BUILDING BLOCKS

There are several main pre-requisities of comprehensive automation with some deserving special attention.Their evaluation in specific conditions of engineering industry and in fact all other industries, provides information of their feasibility, economic effectivness, and suitability of approaches. Of these pre-requisities the following are most important:

- the quality of system design
- suitable and available hardware
- efficient system and application software
- the specialist quality on the design team
- the feasibility and readiness for automation.

Let us orient our attention to main building blocks:

1. Manufacturing processes

For various manufacturing technologies represent manufacturing workcentres the basic modules of manufacturing systems. The integration trends are seen in several aspects.

There is a general trend towards the integration of currently discrete simple operations, into smaller number of aggregated operations performed at multiprofessional workcentres, e. g machining centres featuring a high degree of flexibility. Parallely to this there is another trend towards splitting complex operations into a number of simple operations performed at simple workcentres. The latter situation occurs when the use of multiprofessional workcentres would not be well balanced and when transport between workcentres is easy and inexpensive. In both cases there is a trend towards integrating inspection and manufacturing jobs.

2. Transport, handling and storing

The increased level of automation of manufacturing systems has resulted in a mutual overlapping of shopfloor and inter-operational transport and storing, and possibly also operational handling. The impetus behind this development is a need to shorten transport routes of material, jigs, fixtures, waste and changeable parts of machines. The main benefits of manufacturing systems designed in the way described above are: the elimination of loading and unloading, shorter lead times, smaller shopfloor areas, better time utilization of the transport system, a reduced reliance on having several types of transport and storing equipment, fewer spare parts and therefore easier service. On the other hand there are greater demands on transport control and improved reliability of transport.

The integration of hardware for handling, inter-operational and shopfloor transport, and storage does not affect the system structure of these functions as this structure is essential for the organization of their control.

AGVs have been found to be the most suitable means of transport, handling and storing in automated manufacturing systems. A certain increase has been seen in the use of stacker cranes that can be automated, and as such, used for automation of transport and handling. Flexible manufacturing systems are expected to reduce this need for cranes. AGVs in combination with stacker cranes will be able to store palets also in upper cells. This will further increase the number of functions one equipment can perform. Consequently integration will be brought one step further.

Storing goes hand in hand with transport and handling. Though there is a marked trend towards such an organization of manufacturing processes that would allow material to be transported along the shortest route, storing will remain one of the integral elements of manufacturing. In automated manufacturing, storing must be fully automated from the input to the output.

AGVs are increasingly used for transport to and from stores. They have been found suitable also for inter-operational storing and inter-operational transport. The stores are then installed along the routes of AGVs connecting workcentres in an optimal way, according to the needs of material flow. Such dispersed interoperational and shopfloor stores make better use of the available shopfloor area.

3. Organization of manufacturing

In view of the economic and social factors, any automation of engineering manufacturing processes will require a special integration of workcentres, transport means and stores. Main production includes shops where parts are manufactured, heat treated and finished, stores and shops where tools /jigs and fixtures/, are prepared and means of interoperational transport and handling. The whole process from the input of material to shipment is thus complete.

The structure of auxiliary jobs and maintenance is analoguous, with due respect paid to the specificitios of these jobs.

Also the structure at the level of individual shops has seen a trend towards closer integration of all processes,and a change in the inner quality of the performed activities.

A certain shift in decision making is expected in terms of the organization of manufacturing processes, i.e whether they should be technology oriented or product oriented or a combination of the two.

4. Manufacturing process control

The control of engineering manufacturing processes includes a number of functions ranging from production planning and scheduling over different time horizons, to assigment of operations to individual workcentres and the actual control of material flow and machines and equipment. There are other activities classified under the umbrella of design, process planning or premanufacturing functions. All these activities represent a set of very diverse elementary tasks and their links.

Main concepts of manufacturing control systems may cover following main features:

* conceptual closeness - functional openess
* parallel specification of programs and data
* transition to distributed control
* real time control
* parallel processes on data shared basis
* covering increasing number of computer processed tasks

5. Production management

The logical and methodological content of management and control processes is a basis of the longest service life. For the sake of this study we differentiate three principal functions:

- strategic management and control of a plant
- product development, its design and process planning
- manufacturing control in real time.

5.1 Strategic management and control

Integrated automation must proceed from a well defined concept of development for the coming 20 years. This time span is not accidental. The service life of an automated workshop or a group of workshops or a small plant comes to at least 15 years, with an additional 5 years for preparation set-up, etc. Over this time span the workshop should perform all required operations, although some technological elements may be superceded perhaps two or three times. Therefore the following information must be available: what will the product range and scope of manufacturing be; which manufacturing processes will be needed; what will the production base be like; how many people will be needed to run the operations; which skills will be required; what will the economic effect be; and in what way will modernization be funded?

Long term plans and schedules must be updated approximately every five years and extended by a further 5 years. Planned objectives are based on principal data on perfomance, costs, staff and investments. The time behaviour of the main parameters and their interrelations can be modelled. The process of objective formulation and time behaviour of parameters can be processed on a computer in an interactive mode, with the computer linked to the integrated information system of the plant.

5.2 Product development - its design and process planning

Product development is of crucial importance, though marketing side of the problem is not discussed here. Ways and means must be found that would allow a speedy "Reequipping" in almost all engineering plants, aimed at reaching such a level of development that could be coupled to a truly effective manufacturing control and management. Another group of problems is concerned whit the application of interactive graphics in CAD, CAPP including NC program creation, and operational time and cost information as well as actual control of workshops and workcentres /CAM/.

5.3 Manufacturing control in real time

Operational manufacturing control in real time is the basic tool of sales control and control of manufacturing and other processes. All other activities carried out in the plant are somehow related to the operational control.

This control can be split into two basic areas: operational production planning and schedulling, and management and control of manufacturing processes of real time.

Operational planning and schedulling has been automated for quite a while - it was one of the first processes to which computers were applied. In order to enhance the efficiency of operational planning, information on the state of the manufacturing process at a given time is required so that operational plans could be regularly updated in accordance with the actual state-of-the-art. Otherwise they would lose the characteristics of a plan.

In view of this the importance of manufacturing process control in real time has been enhanced, since it not only affects the actual manufacturing process and suggests optimum procedures, but at the same time provides feedback information for continuous short term updating of capacity-balanced operational plans.

The above mentioned three components of real time management and control are mutually interlinked.

The automated management and control system, which incorporates the subsystem of control devices, is designed in such a way that allows documentation-free manufacturing and inventory control. Characteristic features of an automated and partially automatic system of operational plant management and control - from store rooms to product shipment - can be summed up as follows:

- It is a two-level system /workshop, plant/, of operational manufacturing control and management.
- A hierarchy of process control computers, terminals and sensing devices in the controlled object is establisbed to automatically provide real time information about work-in-process and the state of each transport batch. Consequently, information is readily available throughout the plant /including store rooms/.

- The assignment of jobs to workstations is also automatic. Jobs are assigned according to the actual state of the manufacturing process, on the basis of timely and objective information.
- The system of direct control is designed in view of the planned objectives, i.e. for completely automatic control and management of comletely automatic workshops. Intermediate stages with lower levels of automation have been derived from this expected state. Basic principles applied to all levels of automation are identical.

Conclusion

The integration of components and activities is one of the trends currently seen in manufacturing systems and has brought practical results. To a large extent their successful implementation depends on the modularity of material and data flows troughout these manufacturing systems. Great attention is paid to the modularity of the systems used in comprehensive automation.

Further development and improvement in this area will be affected by demands regarding flexibility, modularity and the degree of automation. Their mutual relations will have to be optimized in terms of economic effectivness and humanzation of work. In addition to technological criteria, other criteria will have to be considered, including ecological factors.

Integration in Manufacturing: From FMS and FMC to CIM

by

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INTEGRATION IN MANUFACTURING : FROM FMS AND FMC TO CIM

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1. INTRODUCTION

The past years of industrial development proved that Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP), etc. should be used to get sophisticated, manufacturing systems of high level of automation. Integrated and/or Flexible Manufacturing Cells and Systems (IMC,FMC, IMS,FMS) intend to be real Computer Integrated Manufacturing (CIM) systems.

A cell - in our concept - generally consists of a limited number (e.g. 3-10) of NC machines, robots, transfer and storage systems, etc. which work under the control of a mini- or microcomputer system, the so called cell controller.

CIM system design and implementation issues are too complex even to speak about real solutions. Even those cases, which claim to be CIM systems are more closed to CIM islands than to really integrated systems. Integration in this case should mean computerized connections in hardware and software from ideas to sales management via design, production control, production, quality control, etc.

Networking of different computers, NC machines, etc. is solved, but standardized protocols became a main point to be provided. Recently the most up-to-date MAP/TOP communication systems are supported by several big computer and industrial manufacturers as well.

2. FLEXIBLE MANUFACTURING CELLS

Manufacturing cells have been proven to be the appropriate size building blocks to get sophisticated FMSs. Generally, a manufacturing cell is considered as a group of one or more machine-tools, robots, adjacent mechanical elements, tool and fixture supporting workstations and an internal transport system (Fig. 1.). Similar cell concept appears in the pilot plant of the ESPRIT project as well. See CIRCE (1989).)

The cell elements have their own local controllers (NC, CNC, PLC, etc.) and each cell has its separate controller. The cell controller functions are performed by micro-, mini-, or supermini computers.

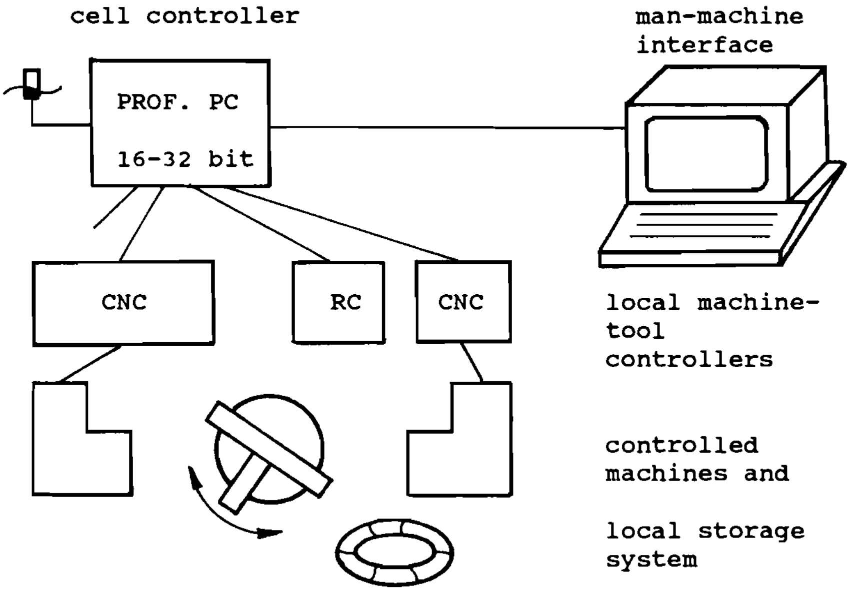

FIGURE 1 A manufacturing cell

A manufacturing system may consist of different types of cells, such as manufacturing, warehouse, transportation, cleaning, measuring and dispatcher cells, etc. (Haidegger, 1984) Each cell may have the same type of cell control computer and similar control software. The cell controllers can be connected via a local area network (recently mainly MAP is suggested). (Fig. 2)

Fig. 2. gives only one possible solution of building up an FMS from smaller units. The same system functions could be achieved by means of a set of NC/CNC machines under the direct control of a central control computer without the cell level controllers. Several other control structures can be constructed and are used in different manufacturing systems. For more details on control structures see Kovács (1989).

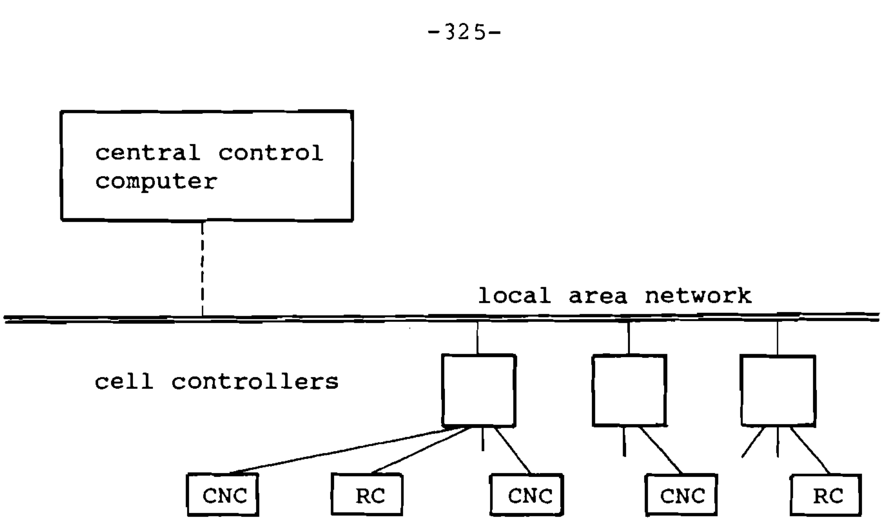

FIGURE 2 A manufacturing system

3. DESIGN ASPECTS OF THE CONTROL SYSTEMS OF FMS/FMC

3.1. Cell oriented systems

Due to the architectural and functional advantages cellular manufacturing systems are appearing world-wide in an increasing number. In cellular construction the cell controllers have only local authority within the cell, and the cooperation of cells is organized in a hierarchical or heterarchical (with distributed intelligence among computers of equal rights) way. Some advantages of cellular systems are the following:

- The cabling can be reduced in comparison to other types of FMS. Reduced cabling decreases costs and noise sensitivity.
- The data base can be distributed among the cells, which results in less data transfer and higher reliability throughout the whole system.
- The system configuration can be modified relatively easily by adding or omitting elements, by regrouping machines. This may result in better system performance and increased production output.

3.2. System integration

System integration is at least a two level problem for manufacturing cells. On one hand, the cell elements have to be integrated to work together as a compact cell. On the other hand, the cells have to be integrated into a larger system, e.g. into an FMS. (For factory size systems two more levels should be taken into account : integration of FMS into plant and integration of plants into the factory.)

3.3. Data characteristics

The data in the system have to be of uniform structure, for easy exchange between the stations. The uniform structure does not only facilitate the operation, but similar or the same data handler modules can be used in different parts of the system software.

Data in the system can vary according to validity in time. There are so called static data, which are considered as constants for very long time periods. There are, however, other types of data, whose validity varies between these two extreme values. Tool offset compensation values remain unchanged for the manufacturing of several workpieces, while cell configuration data are valid at least for a couple of days.

Data can be classified according to their availability, i.e. which system component has a certain type of access to them. Usually most of the data are available for reading in the whole system, writing, however, is more restricted. Inadequate writing of data can cause severe malfunctioning, and therefore must be prevented by using proper data protection and authorization methods.

3.4. Operator interface

Another important issue is the operator interface of cells. As the human operator is not supposed to monitor continuously the operation, he must be provided with an easily operable man-machine interface.

This means comprehensive, easily understandable messages and status display as well as easily learnable command input and way of intervention. One method can be window based screen output and menu driven command input, when the operator is provided with the necessary, and only the necessary support information when a decision has to be made. (Bertók, 1988).

3.5. The FlexCell cell controller

Several research facilities and industrial firms realized that the manufacturing cell concept is advantageous in comparison to big, centrally controlled manufacturing systems and began to develop cell controllers. Most of these controllers were developed using 32 bit microcomputers with high level services.

Taking into consideration our possibilities and industrial demands a flexible manufacturing cell controller system called FlexCell was developed (Csurgai, 1988) with the following significant features:

- In order to ensure the generality, the main tasks have been implemented independently of the specific features of the machines, processes and hardware-software resources.
- The control software runs on an enhanced professional personal computer and it is easily adaptable to other computers. The enhancement is achieved by adding an intelligent slave-processor module to ensure the necessary real-time, high performance communication with the external world.
- The cells are easily reconfigurable, and the cell controllers meet the requirements of system level reconfiguration, as well.

The software design was based on our SATT (System Analysis Technique and Technology) method (Létray, 1985) namely the modules have exactly specified logical interfaces and are arranged to functional layers. There are three functional levels (computer level, cell operation level, and control & supervision level) of the cell operation software.

4. FLEXIBILITY AND SYSTEM RECONFIGURATION

Flexibility in operation can be facilitated by system reconfiguration. Reconfiguration may become necessary in certain situations, when a modified system structure can cope with the production tasks more easily. A few of such situations are mentioned in the following:

- During normal operation better adaptation to changing workload can be achieved by rearrangement of system elements, or regrouping some of them from under the control of one system to another.
- In the case of component failures the operation has to be continued without the defective element, and with the least production lost.
- New elements can be introduced and added to the system, and old elements can be disconnected.

For the configuration and reconfiguration tasks, a good database of all parts, materials, technologies, available machines, robots, controllers, etc. are necessary together with a deep expertise of engineers and economists. This expertise can be put into a dedicated expert computer system.

5. THE FMS/FMC DESIGN PROCESS

When an FMS is designed, the first step is to choose the appropriate cell configurations, which contain the necessary manufacturing, transfer and other units. Based on the parts to be produced by the system, on the technological plans and on the available equipment the configuration of the cells and of the whole FMS can be determined. The FMS design problems are derived from their structure and application. An FMS is a complex (large-scale) discrete-event stochastic dynamic system, i.e. it is hard to follow and understand its exact behaviour, thus FMS design is really a sophisticated task. But considering the great value of the FMS investment and the production of it, it is necessary to estimate the performance and the costs already in the design (and planning) phases.

It is more or less clear that the traditional design techniques are not suitable in the case of a cell or FMS design. On account of the flexibility of interacting FMS components, it is hard to define simple input-output relationships to help in designing them. It means, that no well-known appropriate mathematical procedures can be applied.

When a system cannot be evaluated analytically to get a single solution, simulation is a right way to go. In this case a symbolic representation of the real world (FMC or FMS) is coded into a computer program to evaluate stochastic problems. Though simulation is a very effective technique for dynamic analysis and thus for FMS design, it is short of optimizing ability. The optimal or a satisfactory solution can be obtained through modeling alternative approaches with iteration.

Expert systems use heuristics to get "suboptimal" solutions so they can be applied very usefully in solving practical problems even in manufacturing environments. Although the techniques of artificial intelligence and simulation are different, still they have a similarity: both are dealing with models. The models used in traditional simulation are generally descriptive. AI models can be called constructive ones as they intend to simulate human activities (reasoning, vision, etc.).

The basic difference between the two models is that real problems can be automatically solved by the constructive ones, while descriptive models need human help for solving the task. Considering the properties of the two models, the idea for coupling them seems to be obvious. With this "marriage" hybrid expert systems can be created, and in these systems the advantages of the two philosophies are taken into account.

To support building such hybrid systems some special AI tools have been developed, as languages (e.g. T-PROLOG, TC-PROLOG), and different shells (Futó, 1987). Some hybrid systems are under development in the field of designing and planning FMSs (Heragu-Kusiak, 1987).

6. CELL CONFIGURATION AND RECONFIGURATION

The cell configuration design has two separate steps, which can be done by iterations: the first is to get a pre- or basic configuration which is an "average" of several possible configurations, and the second is the reconfiguration from this average according to the real production tasks or manufacturing situations.

To find the best (or close to optimal) solution we use a hybrid expert system that can get information from different knowledge sources. We call knowledge sources the conventional database, the knowledge base and several computer programs that are based on different kinds of models (analytical and simulation) (Mezgár, 1988).

The system has to perform different tasks :

- selection of machine tools based on the technological plans and the parts' geometries and on the available machine tools
- selection of controllers for the selected machine tools; these controllers must be able to work in connection with the cell controllers
- selection of the material handling equipments (e.g. robot)
- simulation of the manufacturing process

As we use a special tool for running AI-based simulation, the ALL-EX shell (Futó, 1987) connected with programs written in CS-PROLOG, we have the possibility to examine different simulation models combined with the rules of the expert system automatically, to get the optimal solution. Naturally even financial aspects are taken into account.

6.1. Basic configuration

Based on all the previously gotten results the hybrid expert system builds up the hardware configuration of the cell. It defines whether the needed number of parts can be produced in one or more cells in the given time period and gives advice for the buffer capacities too.

6.2. Reconfiguration

The cell reconfiguration should be performed in the case of disturbances, machine brake-downs or when production demands are changing. In such a case the basic configuration is the running one, and the new one is going to be achieved based on the new demands the same way as the configuration above.

When more cells form an FMS, some other, even more complex problems have to be solved. Since cells may interleave each others, virtual cells may be formed by the reconfiguration of several cells within the manufacturing system. This kind of dynamic behaviour of systems poses new requirements for the control of FMSs, but simulation methods can help in all design tasks.

The layout of the FMS, the selection of the type of machines and of transportation systems, etc. can also be designed with hybrid expert systems, however this task is beyond the scope of our recent research.

One part of the FMS design system is under development now, and it uses mostly hybrid models for the design of material handling of an FMS. (Mezgár, 1987).

7. SOFTWARE CONFIGURATION - RECONFIGURATION

We have tried to prepare the cell control software to be as general and portable as possible. However it is natural that there are several pieces of the software which must be rewritten at a new application, or even minor changes of the equipment need new software. For example the test- and diagnostics parts are completely open, thus those must be written individually for every application.

On the other hand some software parts can be omitted in certain applications, e.g. CAD or warehouse cells do not necessarily need tool-change programs, etc.

The process of software configuration is similar to the hardware configuration, but there are two basic differences. The expert system does not have to be connected to a simulation package, as the programs' behaviour should not be simulated. The other difference is, that at the end of software configuration, or reconfiguration process a list will be given with all of the software modules that must be changed, and the reasons and goals of the necessary changes are indicated. In the future we could imagine an expert system which does the rewriting of programs as well, however this is not our goal yet.

8. EXPERIMENTAL RESULTS

8.1. An expert system tool

The design of an FMS cell configuration and reconfiguration should be performed according to the actual production task.

The utilized Expert System Shell is called ALL-EX (Futó, 1987). This is a PROLOG-based system building tool, that is used to build and run stand-alone expert systems. ALL-EX allows to build knowledge bases containing rules, facts and metafacts in an interactive environment having two levels: the shell itself and the CS-PROLOG language. These make it possible to build up a knowledge base and to perform consultations, including simulation steps.

The consultation environment gives several facilities during the execution, e.g. tracing, explanation of the reasoning process, dynamic modification of the knowledge base, uncertain knowledge handling, backtracking, etc.

The ALL-EX shell makes it possible to execute CS-PROLOG (CS stands for "communicating sequential") programs that provide the possibility for building high-level simulation models. In CS-PROLOG a process interaction view of simulation is supported. A built-in backtracking-in-time is based upon an abstract time concept (called virtual time).

The ALL-EX system can change the structure of the original simulation model automatically and dynamically based on logical consequences derived from possibly sophisticated preconditions. Advanced parallel communication mechanisms are supplied (pattern matching, unification algorithm, message sending and receiving) and the system can take over a part of the problem solving effort from the user, with the help of the built-in theorem prover.

8.2. Hybrid Expert System for cell configuration and simulation

In addition to the model of the cell configuration activity in a form of rules, facts and metafacts, we extended our system with an integrated simulation facility that can make use of alternative steps and substitution possibilities in the design process. That's why one can speak about a hybrid system.

Rules and facts are given with a certainty factor, so results are valid only with a computed probability. That's why there is a need for the immediate evaluation of the proposed cell-configuration, using the integrated simulation facility. During a configuration session several solutions can be derived from the general simulation model, where a solution is a special model.

Even during the simulation, in accordance with the existing preconditions, the applicability of the current class of cell configuration alternatives can be determined. It can be clearly demonstrated, that situations might occur, when despite of all possible alternatives having been tried by the backtracking-in-time, the proposed set of manufacturing tools (machines, transport vehicles, buffers, storages, etc.) are unable to perform the required production task. In this case, the expert system tries the substituting facts and rules.

On the other hand, in the case of successful simulation of the cell-operations, important data can be provided about all the necessary details of the simulated process in order to use them as input for other optimizing or selection rules performing further evaluations.

9. CONCLUSION

Manufacturing systems built up of smaller, complex units, i.e. from cells are becoming typical examples of flexible systems. The design and the operation of these cells need new methods to utilize all the embedded benefits of the sophisticated and expensive elements installed for production purposes. The functions of configuration and reconfiguration were derived as the key sequences to be performed with more advanced, intelligent control. The CS-PROLOG based expert system, called ALL-EX seems to be a right tool to tackle this problem. An important feature of the expert system, namely the integrated simulation module, serves as a verification method in the selection of an adequate configuration.

The sketch of the first FMS, the cells of which were designed/configured using our hybrid expert system is given in Fig. 3 (Kovács, 1988).

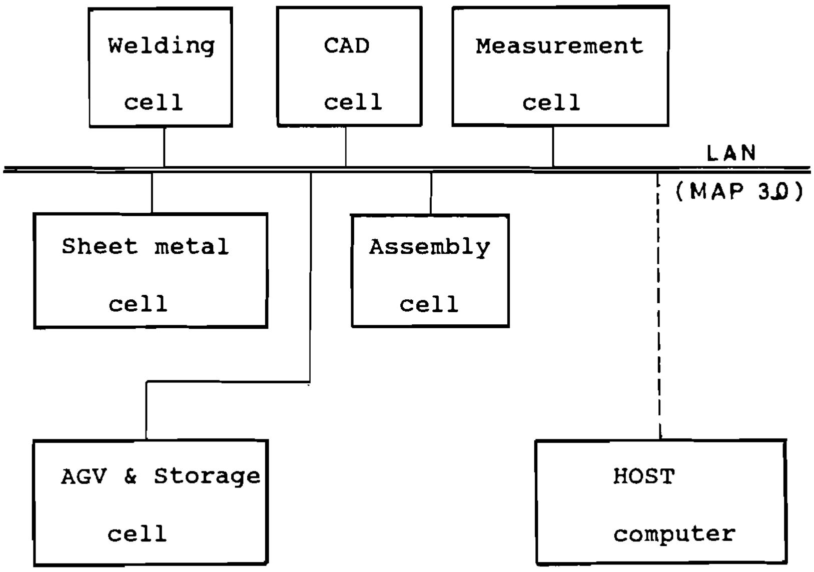

FIGURE 3 A cellular FMS system

As the system is connected to a mainframe, 32-bit HOST computer for running CAPP, CAT and other CA.. programs and it has a dedicated CAD cell it will work as a real CIM system as soon as all parts will be ready to work.

Similar systems of similar philosophies began to work world-wide, but mostly in Japan and in the USA providing a three-shift operation, where the first two shifts are really unmanned, i. e. they work really under complete computer control without human attendance.

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Information Technology in Manufacturing

by

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INFORMATION TECHNOLOGY IN MANUFACTURING

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1 INTRODUCTION

The flexibility of production is achieved by ability to react on changes in the surrounding. Organizational and managerial aspects are key issues of flexibility (Ollus et al 1990, Toikka et al 1990), but the full benefit can be achieved only by use of proper technology. Hence the effective use of the ideas of CIM and FMS needs utilization of automation technology.

Manufacturing automation has taken advantages of progresses in the process industry, because it is much newer than automation in the process industry, which has been largely applied after the second world war. The manufacturing automation can be considered to have started with the industrial introduction of NC-machines and later also robots. Accordingly, the history is about the half of that of the process automation. Although the two fields are quite different there are also many similarities and these are at the moment perhaps growing, because the process industry is also beginning to adopt ideas of flexible production from the manufacturing industry.

The differences between the two fields can especially be seen on the lowest level of the automation. Here automation is usually an integrated part of the process equipment. The tooling machines or the robots include the automation functions as an integrated part of themselves. The automation cannot simply be added to the processing machinery like many solutions in the process industry.

In addition to the lowest level development is going on also on a higher hierarchical level. When connecting the automated equipment together the automation methods are similar to production control methods in the process industry. These methods are dealing with the control of the manufacturing process, but also higher levels like production and product planning, logistics and inventory control, marketing functions, etc are covered.

The rapid development of electronics has naturally been the major driving force for the rapid development of production automation. Increasing efficiency together with decreasing relative prices has been the main factor. This trend is still continuing (see e.g. Ranta 1990). The speed of the development can be seen from the fact that the larger use of microprocessors in the industry started during the 1980s. The capacity of newly announced chips (Huang 1989, Kohn and Margulis 1989, Jelemensky et al 1989) means that a capacity near to that of a super-computer today in a near future may be available to the price of a workstation. Hence we can conclude that hardware will allow efficient use of new approaches. Applications using artificial intelligence, advanced image processing, etc in real time may be quite feasible.

However, automation does not only depend on hardware development. The trends in software are at least as important as those of hardware. Problems in software development are e. g. given as an explanation to the difficulties in many automation product development projects. Also some features in the performance of different types of flexible manufacturing systems (FMS), especially the lower performance of medium scaled systems, are explained by software and communication issues (Ranta and Tchijov 1990). These areas seem to be the most important factors in the use of information technology in manufacturing.

Different aspects of information technology in manufacturing automation are discussed in this paper. Automation can be seen as composed of building blocks, which are tied together by software and communication. The blocks and their interaction are discussed together with some development trends.

2 STRUCTURE OF AUTOMATION

Manufacturing automation can usually be structured as in figure 1. In the control hierarchy of figure 1 the overall control of the production is on the highest level. This function communicates with all other functions which provide it with necessary information. To emphasize the role of the production control module all communication between the other modules is indicated to go through this module, although also direct communication may be arranged in many cases.

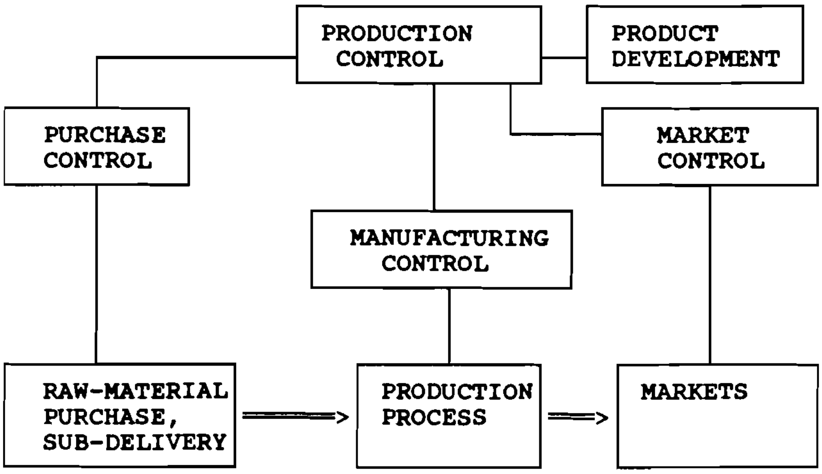

Figure 1. The interaction between functions included in the production control.

Flexibility is achieved by the production control through fast changes of parameters and programs. On the production process level information technology is used to control the functions of machines and tools. The building blocks are mainly software modules, which are distributed into different computing systems communicating with each other and processing information in parallel. Parallel computation increases the capacity of the system and allows real-time control. The distribution allows local computation. This reduces the need of communication and possible disturbances usually remain local.

In the process industry the described approach has been a standard technology for over a decade. In flexible production systems these principles are also applied. Cells, machines, transportation systems, robots, etc. are locally controlled usually by means of microprocessor based technology. They consist of intelligent basic functions which are linked together by the overall control. In the development towards CIM this integrating coordination is essential. An integration is, however, impossible without development of the building blocks. For utilization of e.g. unmanned night shifts local control of all subprocesses and equipment is of fundamental importance. The trends in the development of local intelligence on the control loop level are hence as important as those of communication, production control, etc.

3 LOCAL INTELLIGENCE

Local intelligent functions rely on measurements, where information technology has an important role. These are typically devoted to measuring tooling results, the positions of robots in relation to their targets, positions of transportation equipment and needs for diagnostics. All measurements have to be done in real time, i.e. the measurement must not slow down the operations. This requirement is the main obstacle for a wider automation of many processes.

Although measurement have been rapidly developing there is still much need of new and better measurements. Many of these needs are related to the acquisition of information about the surrounding of the process or machine. Image processing has been used for perception of this type of information.

Vision. Applications in especially robot vision increased during the 1980s. However, the large amount of information in images is an obstacle for many real time applications, because of time consuming algorithms. Also three dimensional image processing is still a problem in many cases. Due to these reasons the pace of business in this field has not been so fast as was usually expected in the beginning of the decade. The slow market expansion has led to difficulties for companies in the vision business.

Because of technical difficulties many image processing solution has solved some restricted problem. Usually some special arrangements like illumination by structured light have been used. A successful application in this field is e.g. automatic seam tracking in robot arc welding.

In the manufacturing process vision is also needed for inspection and sorting purposes. These may be inspection of machined parts, treated (e.g. painted) surfaces or sorting of parts before assembly. In many cases the aim is 100% inspection. Also in these cases special solutions are used, although some commercial image processing system may be the basis.

Many of the methods used in vision applications for recognition and inspection of objects are well known and have been applied in many commercial systems. However, they are not suitable for a deeper understanding of scenes which is necessary in a complex environment like assembly. Here the system requires a variety of data structures to represent its knowledge about perceived images and the application domain. The impact of advantages in knowledge engineering will in the future be considerable (see e.g. Goodman et al, 1989). Different types of systems with a broad scope of image understanding capabilities may be available for complex situations in manufacturing applications.

Tactile sensors and sensor fusion. Tactile sensors can be defined as devices measuring parameters of contact interaction between the device and some physical stimuli. The interaction is normally defined to a touch sensitivity region on the surface of the device (Nicolls and Lee 1989). They are important especially in many robot applications where they form an important class of sensors. Tactile sensors may be simple binary contact sensors e.g. for detecting the presence or absence of touch. More complex sensors may in many cases substitute the need of vision systems in providing data about shape, size, position, etc. Tactile sensors can also produce information which is not common for visual systems, e.g. force measurements. Sensing the slip, i.e. the movement of an object relative to the sensor surface, is also an important task for tactile sensors. A slip sensor may be mounted on the gripper of a robot.

Tactile sensing is still in an early stage of development. Despite of large progress in developing tactile sensors they have not yet made any significant contribution to real applications on the factory level. There is, however, market potential for low-cost, robust and accurate commercial tactile sensors (Nicolls and Lee 1989). Along with the development of the sensors themselves attention has also to be put on the processing of the unique information provided by tactile sensors.

A very challenging use of local intelligence and a broad set of sensing, including vision and tactile sensing, is the need of mobile robots and autonomous vehicles. The perception of information about the surrounding has to be based on the fusion of information from a broad set of sensors. The variety of needs goes from overall navigation to exact manipulation or inspection of work-pieces. A lot of work and international cooperation are going on for development of new navigation and control methods for autonomous vehicles.

Control. The aim of image processing and other information acquisition is to use the information for a better control of the process or the system. Hence the control is the primary task. On the local level information technology is used for calculating actions for machines and actuators. Many of the functions are realized using mechatronics, i.e. integrating measurements and control functions with mechanics controlling the production process.

Flexible, generic, versatile grippers and fixtures for robots and machining systems are in some forecasts (OTA 1984, Ranta 1989) supposed to be available at the end of this century and a lot of work is now going on in laboratories (see e.g. Allen et al, 1989). These are good examples of mechatronics with integration of mechanical actions and electronics performing sophisticated control actions which may contain complicated algorithms working in real time. In these applications new fast chips for processing of signals from different types of sensors have a significant role.

4 INFORMATION TECHNOLOGY ON SYSTEM LEVEL

On the system level the function of the different parts is coordinated. Although most of the local needs for automation are assumed to be available in the near future integration and coordination of different needs are still assumed to need development efforts (Ranta 1989). Much of the problems have to do with complicated scheduling and control algorithms and the huge efforts needed for software development in large applications.

In the development towards CIM the coordination of the whole production system includes many different processes and actions. Communication between the different parts has an important role. The lack of available communication means has been an obstacle e.g. for combining equipment from different suppliers. Standardization of transmit and receive protocols is not enough. As in connection with natural languages the system has to extract "words" and "sentences" from transmitted characters and to understand the idea behind. In production this means standardization of the presentation of machining methods, part descriptions, etc. Only standardization of these higher levels can enable connection of systems from different suppliers.

A lot of efforts has been devoted to standardization of communication lately. One of these is the MAP (Manufacturing Automation Protocol) approach. Due to its large worldwide support it will obviously have an great impact on communication standards. However, the development has been slower than was assumed in the mid-1980s. Standardization processes are always slow and in areas with fast technological development many standards are already old when they appear. This may also to some extent be relevant for MAP, but many principles are independent of the used technology. Because of this and of the large support much of the standardization work in MAP will likely have influence far in the future.

Coordination and scheduling solutions require also large software efforts. In this field standardization is not so far as in the communication area. Most of the solutions are so far tailored for each application. In large applications the scheduling and control algorithms may be very complicated. Hence software development costs become high. Also the management of the software development may be a challenging task.

Means to overcome the rising software costs are standardization and use of modules on one side and new development tools on the other one. A use of standardized software modules enables reuse of developed software. Application specific software is then used only to combine the modules for the needs of the applications like in digital automation systems for the process industry.

The use of modules does not solve the problem with complicated scheduling and control, although modules may help in getting an overview and in decomposition of complicated tasks. Tools like simulation are useful in solving complicated control and scheduling tasks. A lot of simulation software with efficient hardware and graphics has become available for this purpose. Also new workstations for software development are becoming common. In these tools recent advances in software research, especially in the field of artificial intelligence seem to provide some approaches to solve the problems related to software development. The implementation of these means will also need the high processing capacity from future hardware.

5 TRENDS

Trends in systems. The fast progress in information technology may in the future change some features of present manufacturing. The connection between system size and efficiency which could be derived from the IIASA data base is explained by the investments in software and communication. Standardization and use of modules may change the performance figures for different systems. Medium scaled FM systems may very well become more attractive than today.

Despite of their great flexibility small compact systems have had quite isolated use. The structure of their information processing and communication may in the future also be an obstacle for larger integration. Simple solutions may not have capacity to meet the needs of a large integration approach. Hence small systems seem to remain as effective flexible solutions in independent automation islands.

General trends. Manufacturing is going toward production in a network economy. Production chains with large connections to sub-deliverers and distributors are essential. Also the cooperation between the markets and the production is a part of the network which is worldwide. An important part of manufacturing is then operation in the network, i.e. managing material- and information flows. Hence the importance of logistics in manufacturing is growing.

A mean to respond to the new demands seems to be flatter organizations. Hierarchies are lowered and many special functions are separated to independent units. These smaller units can more easily adopt themselves to changing conditions. They are more flexible.

Most of the approaches in manufacturing automation have been hierarchical. Some overall coordination divides the tasks between stations and it also controls the performance of the tasks. Scheduling and overall control are also the most difficult and most expensive parts of manufacturing automation. Accordingly we can ask whether production needs hierarchy. Could the overall control and scheduling be eliminated? Could the different machining centers and other processing units work independently like the companies in a network economy? Research in this direction is going on in laboratories. When e.g. a new product is to be produced, offers for its production are asked from the production equipment. The manufacturing can be given to some processing units based on the offers. This type of approach and other ones seem to be very challenging research topics, when we are going towards large manufacturing integration and CIM.

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5. ORGANIZATIONAL AND SOCIAL IMPACTS

Organizational Adaptation and Advanced Manufacturing Technology

by

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Organisational adaptation and advanced manufacturing technology

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Abstract

The emergence of powerful manufacturing systems based on information technology opens up significant opportunities for firms across the entire industrial spectrum to improve competitiveness. Computer integrated manufacturing offers better control over scarce resources, more productive use of equipment, energy and materials and, above all, better service to the customer in terms of flexibility, responsiveness, quality and support. Increasing awareness of such potential gains has helped fuel a boom in investment in advanced manufacturing technology such that growth rates for some items of technology are running at over 20% per year.

However it is becoming increasingly clear that simply investing in advanced technology is insufficient to guarantee these benefits. Evidence now indicates that the way in which it is implemented is the critical determinant and most of the emphasis in this process is on organisational change. Put simply, it is necessary to engage in significant organisational change in order to obtain the full benefits offered by advanced manufacturing technology.

Such organisational changes are required along a number of dimensions including the pattern of work organisation, of skills profiles and distribution, of functional integration of centralisation/delegation of control and in the overall organisational culture. This paper reports on research with computer integrated manufacturing technologies and identifies some of these key dimensions of change. It goes on to explore some of the possible mechanisms for effectively introducing such changes within organisations.

Organisational adaptation and advanced manufacturing technology

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Introduction

Much is made these days of the 'revolution' in technology which IT represents. Some relate this to a theoretical perspective - for example, economists who argue that it represents the next major 'long wave' in global economic development and is giving rise to the emergence of a new 'techno-economic paradigm. [1] Certainly at the level of the individual firm in both manufacturing and services such technologies are having a major impact on many of the dimensions commonly associated with competitiveness price, quality, flexibility, etc. Considerable change is evident also on the supply side for such technology. In the area of manufacturing, for example, the growth rates for supply of IT based items of equipment often run over 20% per year, with a predicted sales volume of several billion dollars by 1990.

One of the key features of the revolution in manufacturing which this technology has brought is a pervasiveness which means that almost any task is susceptible to automation. These days even the smallest and most obscure of industrial sectors is a potential user of some form of IT, and the technology is diffusing rapidly in both the industrialised and the developing world. Yet even this is only part of the story. The emerging view is that simply using an IT based piece of equipment to replace a traditional one is often akin to buying a motor car and then continuing to drive it at a slightly faster pace as if it were a better kind of horse. Such substitution in discrete fashion tends to help us do what we already do a little better. But the alternative - with IT , as with motor cars - is to use it to open up completely new and much more powerful ways of doing things - an *augmentation* rather than a simple substitution. [2]

Thus instead of simply using IT to substitute for discrete pieces of equipment we are now seeing the emergence of manufacturing systems replacing complete stages in the manufacturing process with new and sometimes radically different ways of working. For example, in the design area 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 doing the same task except with an electronic pencil.

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[1] C Perez and C Freeman, 'Structural Crises of Adjustment, Business Cycles & Investment Behaviour' in G. Dosi (ed) Technical Change & Economic Theory, Frances Pinter, London 1989

[2] For a detailed discussion of this, see J Bessant, Fifth wave manufacturing - the management challenges of advanced manufacturing technology, Basil Blackwell, 1990 (forthcoming).

The first change is that the activities of design and draughting have converged whereas before much of the design departments work was laborious drawing out 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 enormous 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 CAD systems make use of information coded in electronic form, it follows that other systems such as those for computer aided manufac- turing which also use such information can be linked in 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 and 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, imporved quality, better machine utilisation and much improved customer service.

This pattern is repeated across the manufacturing spectrum, for example, in flexible manufacturing systems, or integrated suites for computer-aided production management. The target towards which such systems are moving has been labelled computer integrated manufacturing and 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'.*

Of course, such integration does not stop at the boundaries of the firm. 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 minimising the inventory held within the chain.

Such developments towards CIM do not just offer considerable improvements in traditional ways of making things they 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, improved delivery performance, to emphasise 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 in this context is seen as a major and valuable competitive weapon. For example, table 1, below, indicates the way in which this technology can contribute to dealing with some of the major concerns voiced by European manufacturers in a recent survey.

Table 1: CIM - 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	Reduces 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

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[1] Based on the INSEAD/Boston University/Waseda University and others 'Manufacturing Futures' survey. See, for example, K. Ferdows and A De Meyer, 'Flexibility - The Next Competitive Battle' INSEAD Working Paper WP/86/31, Fontainbleu 1986

The idea versus the reality - implementation.

Although such advanced manufacturing systems clearly hold out considerable promise for improving performance along several dimensions of competitiveness, actually achieving these benefits is not a simple process. Many firms have committed themselves to major investment programmes only to find that they cannot get the technologies to perform successfully or that the expected benefit take much longer than anticipated to materialise. 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 underutilisation of the potential. For example:

* in 1989 the UK was reported to be investing in CIM at a rate of nearly £2bn /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 achieveing the two primary goals it claims to resolve i.e. inventory reduction and adherence to deadlines".*[1]

* in another UK 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 of 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".[2]

* 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"* [3]

* in a research programme on advanced manufacturing technology users carried out on behalf of the UK 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*

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[1] A. T. Kearney Consultants, ' Computer-integrated manufacturing : Competitive advantage or technological dead end?", 1989 London

[2] C. New and G. Myers, Manufacturing operations in the UK, British Institute of Management/Cranfield Institute of Technology, 1986.

[3] G Waterlow and J Monniot, ' The state of the art in CAPM in the UK', International Journal of Operations and Production Management, 1987

major problems and long delays had to be experienced in bringing the systems up to expectations"' [1]

* another UK 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"* [2]

* recent evidence from the USSR concerning flexible automation (discussed at length elsewhere in this volume) reports 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".* [3]

Examples of this kind are increasingly found in the trade and technical press as users acknowledge the major difficulties involved in effectively implementing advanced manufac- turing technology. This is not to say that AMT has been oversold but rather to recognise that its successful implementation is more complex than simply signing the cheque and authoris- ing its delivery. In the field of office automation, Strassman suggests that it is often the case that results depend little on the amount invested but a great deal on the management of the implementation process. [4] Jai Kumar makes a similar point in comparing the use of essentially similar flexible manufacturing systems (FMS) in the USA and Japan. [5] He found that the Japanese systems were both more flexible and more productive than their US counterparts and his conclusion was once again that the key to the difference lay in the way in which implementation and operation of these systems was managed.

The recognition that there are particular management skills associated with implementing technology is growing. A number of influential reports are now circulating which draw attention to the need for education, training and development to support the increasing depen- dence on technology which advanced industrial nations are likely to have. But this poses an important research question - what has to be managed? Is it simply project management or is there a more fundamental change

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[1] B Burnes, Integrating Technology, Integrating People, Production Engineer, September 1988

[2] J Bentley, reported at a seminar on Integrated Manufacturing , 10/5/89 in Birmingham , and published by IFS Publications, Kempston, UK.

[3] Sotsialisticheskaya Industriya, 16/3/88, reported in S Glazev, 'Integrated automation in the context of structural changes in a modern economy', paper presented at ECE Seminar on CIM, Botevgrad, Bulgaria, 25-29 September, 1989

[4] P Strassman, quoted in an interview in *Computer Weekly*, 29/9/88

[5] R Jaikumar, 'Post-industrial manufacturing', Harvard Business Review, November 1986

taking place which requires a new and complex managerial and organisational response?

What has to be managed?

There are, in essence, two kinds of organisational response to new technology. The first is a response to the kind of discrete substitution which we saw earlier and this essentially reflects the familiar learning process which we associate with new equipment or with the manufacture of new product ranges. Thus it involves acquiring new skills and developing familiarity in the use of the new equipment so that, over time, the full benefits emerge.

But the second reflects the augmentation effect which only begins to emerge when some degree of integration takes place and where new ways of operating become possible. At this level there is not only the challenge of learning along familiar dimensions such as skills acquisition, but a whole new set of issues raised by the need for organisational integration. These would include structural changes (such as the changing role of functional differentiation between departments), work organisation changes, hierarchical changes (associated, for example,. with the devolution of autonomy), strategic changes (to exploit the new opportunities which technology opens up) and finally - but perhaps most important of all - cultural changes - changes in 'the way we do things round here'. We believe that it is in these areas that the key management challenge now lies.

In our own research on the diffusion and implementation of AMT we have frequently encountered cases of firms which were able to obtain significant benefits from the use of AMT. For example, many FMS users were able to get reductions in inventory levels of 70% and cuts in lead time of similar magnitude. But it is often their view that the majority of the benefits which they obtained from their investments came not from the physical systems themselves but from the organisational changes which they catalysed.

Nor should these findings be seen in isolation there are many other reports with a similar message. Whatever is responsible for the improvements in manufacturing agility and competitiveness is not simply a function of new equipment it also has a strong organisational dimension.

This view is given further impetus when we look at other reports of significant performance improvement in manufacturing. For example, a major telecomunications equipment supplier was able to reduce inventory by over 70% and to increase flexibility such that its original lead time of 14 weeks could be cut to a matter of hours. At the same time its quality record improved dramatically. In another case a firm in the engineering sector was able to cut its work in progress from 15,0000 units down to 1000. Again this was accompanied by improvements in quality and in flexibility the firm becoming able to offer much better customer service including rapid response to changing needs.

Another firm in the shoe industry was able to cut batch sizes down from 1800 to 18 and still produce economically and to a higher quality standard than before. In the process its ability to respond flexibly and fast to the fashion market was massively increased and it was also able to cut inventories and the factory space necessary to hold them.

In each of these cases the benefits were obtained with no investment in AMT but rather by concetrating on organisational changes, primarily associated with the Japanese derived ideas of total quality management and just in time production. These were not cost free innovations; they incur significant costs in the training area, for example but they were more rapidly implemented and involved much lower costs than investments in hardware would entail.

It is important not to see such examples as alternatives to AMT but rather as complementary to it. That organisational change can contribute to improved flexibility and quality should not surprise us any more than the fact that manufacturing systems based on advanced computers and machines also require organisational change to make them work. These findings simply remind us of the original and broad nature of 'technology' which the dictionary defines as ' the useful arts of manufacture' and which is essentially a system involving both tools and organisation around using those tools.

It is this point which helps us answer the question of what has to be managed in an AMT system it is the total system, not just the physical components of computers (and their accompanying software). In those cases where AMT has failed to work properly or to deliver its full benefits the problem lies in the relative neglect of change along the organisational dimension. As Perez points out , there is a mismatch of the technological and the organisational paradigm and this threatens to retard the speed with which change using advanced technologies can take hold. [1]

Dimensions of organisational change

Work within the IIASA CIM programme has included research aimed at mapping the dimensions of organisational change required to support the effective implementation of advanced manufacturing technology. Amongst issues which are of relevance are:

* **the need for development of skills** - integrated automated systems require skilled resources in two key areas: to support the implementation project and to support the long term operation of the system. For the latter there are already serious problems of resource shortages at the level of technician and above. The pattern of convergence observed in the technology is thus reflected in the type of human resources required to support integrated manufacturing systems. As systems are becoming more physically integrated - bringing a number of discrete operations into a single complex cell - not only is there a considerable shift in the balance of direct to indirect workers, but those direct operators who remain become responsible for a much more complex and concentrated system.

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

* **functional integration -** As technology brings different areas of the firm together, it becomes important to ensure that the problems of interdepartmental boundaries are minimised. In some cases this may lead to the creation of new roles or groups, either on a temporary (task force, project team)or a permanent basis. For

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[1] C Perez, 'Microelectronics , long waves and world structural change', World Development, **13**, (3), 1985.

example, there is the need - itself facilitated by moves towards CAD/CAM linkages within firms - for the design and production departments to work closely together to develop products which are suitable for manufacture on integrated systems. Such a "design for manufacture" philosophy is of particular significance in the flexible assembly automation field, for example, where small modifications to the design of an item can eliminate the need for complex manipulation or operations within an automated system. In one case we examined, redesign of the product led to a reduction in the number of operations (handling and machining) from 47 to 15 - with accompanying improvements in product quality. As the manager involved put it, " FMS is going to drive the shop - but it's also going to drive the people who design the product and the production engineering...those parts have got to be made on this investment if we are to justify it".

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

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

* **work organisation** - At the level of the shop-floor, considerable changes are implied for the pattern of work organisation. With greater reliance on a small group of workers and managers comes the need to look for models of production organisation which move away from task fragmentation , division of labour and control by external regulatory systems of sanctions and rewards and to evolve alternatives based on small autonomous working groups, with high flexibility and internal control.

In spite of the fact that overall numbers of direct operators decline, the decision about how to train and use those who remain is important. Here there is growing debate about whether traditional patterns of work organisation based on the ideas of Taylor and Ford are neces- sarily appropriate in the case of integrated systems. Attempts to develop a fully automatic factory - that is, one with no human intervention whatsoever - are unlikely to meet with much success because of the enormous risks and costs associated with developing suitable software to control such systems. As one researcher from the Federal Republic of Germany puts it, "most managers and production planners follow a strategy to replace human work still further by enforced use of computers on the shop floor and in the technical office in an integrated manner. Since this strategy is in danger to create new problems, the growing minority seeks to avoid them by reorganising production and rearranging the division of functions between man and machine in a way that makes use of the worker's skills instead of reducing them to operating servants". [1]

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

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

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

* **inter-firm links** - In parallel with these organisational developments within firms has come the gradual realisation that the manufacturing process consists of a series of firms and links. Increasingly the relationships between firms are being recognised as being as important as the firms themselves in termsof controlling costs and adding value. Technological process innovation and investment cannot, therefore, be considered solely in the context of individual firms. Rather, strategies must be developed which take into account the material and component suppliers and the distribution system.

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[1] P Brodner, in P. Brodner et al, (eds), New technology and manufacturing management, John Wiley, Chichester, 1990.

For example, in the UK automotive and electronics industries there are clear signs of consultation between component suppliers and their customers on investment in CAD. In order for such systems to operate successfully a number of new approaches to buyer/supplier relationships have developed from the traditional model, often based on conflict, to a "resolved" model which relies upon a "common sense" trust and concern for mutual development. [1]

Conclusions

This paper has briefly summarised some of the trends in advanced manufacturing technology and suggested that there is a major need for organisational adaptation. It has also indicated some of the dimensions of such change which appear to be significant in determining successful implementation. But there is much further work needed to identify not only which dimensions are relevant for which types of organisation and technology but also for beginning to identify mechanisms for achieving such organisational change smoothly. Some 'blueprints' are already available the cases described earlier suggested that major benefits could come from following the approaches of 'just in time' production and 'total quality management'. Others are being rediscovered in the literature of the1960s in the area of organisational development such as matrix management or even in earlier forms such as group technology and socio technical systems design.

Whatever the emerging forms, it is clear that there is a considerable challenge for manufacturing as it approaches a new century. Just as factories of the 1800s would be unrecognisable today, so we need to move towards what may be a radically different model for the future. The ability to move from what some workers call the 'Fordist' techno-economic paradigm to a 'post-Fordist' alternative is, arguably, the dominant issue which will determine competitiveness between manufacturers throughout the 1990s and beyond.

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[1] R Lamming, Towards best practice, Occasional Paper 5, Centre for Business Research, Brighton Business School, Brighton Polytechnic, 1988.

Macroeconomic Employment Effects of CIM-Application

by

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Macroeconomic Employment Effects of CIM-Application

1. Problems

The relation between technological progress and employment has been discussed in social sciences for a long time. The discussion has been focused on two problems over and over again:

- the labor replacement potential of new and labor-saving technologies, and
- the changes in the qualification requirements caused by technological progress.

The discussion concerning the quantitative and qualitative employment effects of technological progress has been particularly intensified when the labor market was not balanced /47/.

In recent years, numerous studies were published regarding accelerated use of high technologies, especially flexible automation, and their effects on demand for manpower as well as on labour skills.

There has been widespreed agreement in those studies to the effect that intensified introduction of flexible automation may lead to clearly visible savings on manpower at company level and also results in substantive changes concerning demands on the qualifications and trades needed. There has been agreement also to the effect that the position of CIM application so far reached in highly advanced countries has not yet resulted in palpable economic change to the quantitative level and setup of manpower deployment. Divergent and even contradictory views have been expressed on medium-term and long-term consequences of CIM intensification on level and structure of demand for labour in a real national economy. In many studies in which those consequences were analysed for highly advanced countries, misgivings were emphasized that intensified application of CIM might entail dramatic rise in unemployment, while other authors suggested that labor-saving effects might be offset by other developments, such as expansion of production owing to rising domestic demand and an improvement in export markets, last but not least, for lower production cost.

Extremely short-cut conclusions have quite often been drawn in this controversy as to macro-economic effects of information technology but were usually based on observations at micro-economic level. Such an approach usually led to overestimation of two phenomena: growth of labor productivity, when looking at replacement following installation of high-tech facilities, say, industrial robots, or potential economic growth at national level, when looking at the most strongly advanced companies and their rates of expansion. Such fallacy may be avoided for more adequate assessment of effects, but this would require a better substantiation at micro-economic level for macro-economic judgement of the topic /39/.

Differenciated rating of effects has been additionally attributable to the use of different methods of forecasting as well as to different assumptions made of application potential, rate of diffusion, and productivity effects expected from high technology. Growing importance is being assumed by the question for methods particularly suitable for appraisal of technology sequences. A "royal path" for good appraisal of macro-economic effects resulting from technological development, therefore, is intensively discussed in the economic literature.

The following three major approaches to empirical investigation of employment effects of change in technology may be outlined, with some reference being made to a classification by WEISSHUHN /50/:

(a) Descriptive studies of case study nature and often based on inquiries at company level;

(b) Limitational approaches, such as input-output-models or the manpower requirement approach, which implicitly rule out possibilities for substitution between production factors;

(c) Econometric investigations on theoretical aspects of production in an attempt to quantify employment effects of technological change by means of statistical methods.

Input-Output models appear to be of particular interest for good appraisal of those employment effects which are recordable at the level of a national economy /cf.3,7,14,17,19,23,27,28,33,34,35,37, 39,42,43,51 /. BROOKS /7,p.91/ characterized the Input-Output-approach as method, which "provides the most rigorous method for projecting employment effects of new technologies because it is capable of accomodating economy-wide effects arising out of the linkage among sectors and thus of tracing through the system-wide impacts of introduction of a particular technology".

Input-Output analysis is understood as a linkage between the micro- and macroeconomic investigation level /14/.

An important precondition for using the input-output approach for such investigations is the elaboration of detailed occupation-by-sector matrices (1) in which the single labor category makes it possible to adress the labor impacts caused by CIM application.

Such matrices which are internationally comparable was elaborated for different countries and for different time points /3,21,29/.

The computed internationally comparable occupation-by-sector matrices allow a very detailed insight into the occupational structure within the economic sectors and their development.

In the following

- an overview about the data basis shall be given;
- the possibilities and the methodological limits which have to be considered in investigating the employment impacts of CIM application with the help of labor matrices shall be shortly discussed;
- it should be make an effort to estimate the potential of employees which may be influenced by the CIM application;
- it should be try to consider the technology induced employment effects in a broader context, namely in the context of the three-sector-theory.

2. The Data basis

Occupation-by-sector matrices are available for many countries. The main data sources for these matrices are censuses and microcensuses or specific surveys (as in the U.S.A.). In these matrices usually national classification systems of the occupational unities as well as of the economic sectors are used. In order to achieve international comparable occupation-by-sector matrices it is necessary to convert the national labor matrices so that

- the occupational categories are classified according to the "International Standard Classification of Occupations" (ISCO 1968) /26/ and
- the economic sectors are grouped according to the "International Standard Industrial Classification of all Economic Activities" (ISIC 1968)/25/.

The precondition of these computations is the availibility of conversion lists between the national used classification systems and the international classification systems ISCO and ISIC respectively. As these conversion lists are available for the author only for some countries the investigations have to be restricted to the following countries: FRG, U.S.A., Austria, Finland, Sweden, the Netherlands (2).

The classification of occupations as well as of sectors is according to the 2-digit classification of ISCO and ISIC respectively. For some countries is was possible to subdivide the occupational groups and the sectors respectively which are important for the investigation of employment effects of CIM application.

3. Advantages and limitations of this approach: Some remarks

The most important advantage of detailed occupation-by-sector matrices is the possibility to adress the sectors and the occupational groups which are influenced by CIM application. By these means it is possible to estimate the potential of labor forces which may be directly effected by this technology.

Occupation-by-sector-matrices ,coupled with input-output models, has proved to offer a substantial advantage, in that consideration is possible not only of effects on demand for labor which occur in direct concomitance with the use of high technologies proper, but also of effects resulting from production and application of CIM in pre-connected or post-connected supplying or processing industries. Input-Output models for assessment of employment effects caused by the use of high technologies have been repeatedly described in the literature /14,17,23,30,34,35,36,37,42,43,51 /. A serious appreciation of these modells is given - among others - in /1,3,6,7,19,27,30/.

But it should be noted that occupation-by-sector matrices do not allow the reflection of all important socio-economic aspects induced by technological progress. Some of the methodological limitations of this approach shall be discussed in the following (3):

- In literature is pointed out that just difficult quantificable effects of CIM application (e.g. change of working and living conditions) are among important than those which are easier quantificable (e.g. structural change of labor demand). AYRES underlines: "... the social importance of various issues may well be in inverse ratio to their quantifiability" /2,S.1/.

- It is necessary to combine the heterogenous diversity of wor king places for groups, which in about the same way are affected or influenced by technological progress, in order to be able to estimate the basic influential tendency of the technological progress on the manpower demand /40,48/. This subdivision into groups on the microeconomic level should be organized for such structural features which can also be registered on the macroeconomic level.
  On the macroeconomic level the qualification can be projected empirically in most of the cases according to the formal educational level (highest graduation level), acc. to the vocational classification, acc. to the position in the occupation (worker, employee etc.), acc. to performance level (senior staff or "simple" staff etc.) or according to the main functions (manufacturing, managing etc.). "All the concepts of projection of the qualification have their specific advantages and disadvantages, which have to be evaluated with regard to the background of the given problem, but which finally are authentic by the availibility of data." /41,p.10/
  There is no doubt that it could be very useful to analyze the composition of qualification, occupations and tasks of employed persons in their correlation, in order to be able to estimate influences of the scientific-technical progress on manpower demand /11,12,13/.
  The occupational classification is considered in general as an unsufficient instrument for estimation of required changes in qualification, when new technologies spread quickly. Professions

are flexible by nature and adopt to changed requirements in many ways.

Task are normally seen as a more exakt description of contents of the occupation, since they are more homogenous than professions in a desaggregated form /see for example: 20,49,50/.

However, in this evaluation the following should be taken into account: One objective of IIASA's CIM project was to make an international comparison of work expenditure structures /3/.

Functional characteristics (i.e. tasks) are only suitable to a certain extent, since they are made up according to the nomenclature of the respective countries, if such data ever exist. Adaption of different national nomenclatures seems hardly to be possible. On the other hand it is easier to calculate international comparable labor matrices /3,5,6,/.

In this connection it should be mentioned the so-called "means of work concept" /44,45,46/ which seems to be specially useful to reflect employment effects of technological change on macroeconomic level.

In this concept employed persons are grouped according to tools, machines, plants they use in their work and which means of work they use most. The basic idea in this can be demonstrated in the following example: If about a person is known that he or she works as a skilled worker at a lathe, it is quite reliable to conclude in which occupational position, with what qualification what kind of articles is manufactured in a certain environment. The feature "means of work" thus gives access to other categories of work. It provides information about occupational compositions and their change in the course of time.

Therefore in the first place it is necessary to combine the used means of work for homogenous groups. "A criterion for this form the steps of mechanization and automation ...,another the function of devices and their application..." /46,p.19,20/.

The following example demonstrates that interesting structural patterns may become obvious: In the 1985 microcensus in the FRG for instance the number of 224000 data processing specialists/data typists is mentioned. This number refers to "crucial activities" of data processing (programming, operation of data processing units, entering data etc.). From this number of employed persons operating computers, terminals etc. cannot be concluded on the basis of microcensus for professions. Following the concept of functional characteristics more than 300000 persons stated that their main activity is data processing. Considering the statement about the used means of work it turned out that about 4.5 per cent of the employed persons (about 900000) use computers as their mainmeans of work. This corresponds with a multiple of the result from occupational statistic data /46/(see: tables 1 and 2). Moreover, attention must be paid to the fact that the expansion of application of program-controlled means of work takes place in so-called temporary users.

These remarks will reveal that likewise the classification of employed persons for functions is preferable in comparison with the occupational classification, when changed qualification requirements due to technological progress are to be investigated.

- The employment effects can only be addressed in the labor matrix according to the classification used. In these matrices are only reflected such occupations which are established and well documented in official statistical sources. But CIM application - like any other basic innovation - creates also a demand for new professions. The basic feature of these new occupations is the applied use of computer control /46/. But it is necessary to consider that only some basic innovations are able to stimulate the introduction of new occupations. DöRFER et.al. /10 / analyzed 40 basic innovations which occured in the period 1680-1970. Only 13 of these have created new occupations (figure 1). They emphasized that the share of employees working in so-called new occupations is overestimated. Only one fifth of all employees in the U.S.A. are working in such occupations which have been created in this century. In the U.S.A. only 3 % of all current occupations have been created since 1950. DöRFER et.al. concluded that in the year 2000 in the FRG only 10...12 % of all employees will be working in such occupations that were unknown at the end of the 1970s. The demand for employees with new occupations could be met by "arrivals" from vocational training, universities etc./10/.
  However, the demand for new skills and professions caused by CIM application can hardly be investigated using this approach.

- The effects of CIM application can only be addressed according to the sector classification used. But in each column there is reflected an "average" technology of the corresponding (more or less aggregated) production process. An innovation like CIM caused exceptional effects which can hardly be adequately reflected in "average" technologies.

- In this matrices the employees are usually assigned according to the highest degree of professional education. The qualification which the employees have been possessing besides of their highest degree of professional education is not reflected in the occupational figures. This problem is important just because the qualification of the employees which is really used in the different production processes depends in no small degree on the qualification behind the so-called highest educational level. In this connection it should be considered the important role of reeducation and retraining in innovation processes like CIM which could lead to a second (or third ...) qualification.
  Besides of this problem it has to be considered that the employees are included in the labor matrices according to the finished vocational training (i.e. the highest degree of professional education). Hence it is impossible to analyse the utilization of the employees' qualification in the production processes. This problem refer to the efficient use of the available qualification potential.

- Changes in the occupational structure are not primarily the result of technological progress. The occupational structure is - besides of the technological progress - influenced by various factors (see: table 2). Hence, the changes in these structures can not be explained as exclusively technology induced changes.

4. Employment effects of CIM-Application :The potential

As mentioned above occupation-by-sector matrices can be used to elaborate the potential of the labor force which is influenced by CIM application. This requires to estimate

- the sectors where the CIM-technology is mainly applied,
- the occupational groups, which are mainly influenced by this technolgy.

Without doubt: The metalworking industry is - strictly speaking - the typical sector for CIM application. This statement do not exclude that also in other manufacturing sectors (see: table 4) many efforts have been (and will be) done to apply this technology. But the typical processes for CIM application can be observed in the metalworking industries. The position of the metalworking industries within the manufacturing industries and the national economy respectively in the investigated countries can be shown from figure 5.

Different opinions could exist concerning the occupational groups which are influenced by this technology . The author assumed that the occupational groups given in table 6 are mainly affected by CIM application. This supposition does not claim to be the last resort. If a classification of the influenced occupational groups is more well-founded the estimations could be revised. In this respect the following remarks should be understood as a contribution to discussion, and not more ...

The shares of these occupational groups within the total number of employees is given in table 7 (4). The tables 8 and 10 show the shares of the considered occupational groups on the total number of employees in the manufacturing sectors and the metalworking industries respectevily. In the tables 9 and 11 there are given the shares of the manufacturing sectors and metalworking industries respectively on the total number of employees of the investigated occupational groups.

If one acknowledge the defined sectors where the CIM technology is mainly applied and the occupational groups which are mainly influenced by this technology than the potential of employees which may be influenced by this technology amounts to approximately 5 per cent in the U.S.A. and the Netherlands, to 6 per cent in Finland, to 9 per cent in Sweden and Austria and to almost 11 per cent in the FRG. This potential is not to much!

It should be emphasized that these figures refer to the directly influenced employment potential. Hence, in this estimations the indirectly influenced labor force - which can only be estimated using input-output-models - are not considered in these figures. Besides it should be emphasized that these figures are not identical with the replacement potential.

5. Technology induced employment effects in the context of the Three-sector-Hypothesis: Some remarks

The computed internationally comparable occupation-by-sector matrices allow a very detailed insight into the occupational structure within the economic sectors and their development. In order to recognize - and generalize - the tendencies of development it seems to be useful to proceed from aggregated figures.

It seems to be useful so much the better if one tries to estimate the influence of a certain technology (e.g. CIM) on the structural change within the economy in the long run. In the author's opinion a useful approach is the tree-sector-theory.

The Three-Sector-Theory mainly founded by FISHER /16/ , CLARK /8/ and FOURASTIE /18/ simplified postulates the following development pattern: The production structure which is mainly based on the agricultural production (i.e. the primary sector) was displaced in the process of industrialisation by the secondary sector which contains the manufacturing sectors. In the second half of the 20th century in the developing countries there has been established a production structure which is characterized by an increasing share of the tertiary sector. The tertiary sector comprising the service sectors has been developed to the dominant sector.

This development is not only characterized by an increasing importance of the tertiary sector. Similarily there can be observed significant changes in the occupational structure which is - according to BELL /4/ - one of the most important feature of this postindustrial society.

Changes in the technological and economic structure (i.e. sectoral structure) are accompanied by changes in the contents of work (i.e. occupational structure). Generally the postindustrial society is characterized by an increasing importance of "academic services". This will lead to an increasing importance of higher education and to the emergence of an professional ("academic") class. This is typical for the postindustrial society in the same way as the semiscilled worker who was typical for the industrial society.

The most important consequences for the employment system which result from the process of an increasing importance of the tertiary sector can be summerized as follows:

- The dominance of the tertiary sector does not mean that the importance of industry has been absolutely reduced. Rather the continously increasing output of industry will be produced by fewer and fewer employees. There is emphasized that the potential to increase the labor productivity in industry exceeds this potential in the tertiary sector.

- There is generally the tendency to an increasing supply for jobs in the tertiary sector. But not all service sectors will be extended. For example, also in future the houshold services will be very expensive so that they will not have an siginificant impact on employment. The most important employment effects are expected especially in health service, in the educational system and the recreational sector, but also in science and research /22/.
- The share of the white-collar-jobs will be extended so that the transition to the postindustrial society is generally accompanied by an increasing qualification level.

It should be considered that there was pointed out some essential objections to this theory. Among others the following arguments were advanced in order to refute the hypothesis of the increasing "tertiarity" /15,38/:

- The definition of the sectors seems to be arbitrary.
- The production of new goods retards the demand on services.
- Expansive services will be substituted by "self-made" services.
- The extension of public services is confined by the yield of taxes.
- It seems to be possible that an unexpected increase in labor productivity will be occured in the service sectors.
- In countries where foreign trade plays an important role the manufactoring sectors will have a great importance also in future.
- The subsidy policy of government favours the primary and the secondary sector.
- Inflationary tendencies and rapid changes in the price structure have an influence on investment activities and thus on the rationalisation activities.

However, empirical analysis have verified this theory! This can be recognized for example from table 12 but also from figure 2 where the development of the sectoral structure of employees and GNP respectively in the FRG is given. The figures in tables 14 and 15 which were estimated using the occupation-by-sector-matrices also bear out this hypothesis. In these tables are given - besides of the sectoral distribution of employees - also the occupational structures. The occupational categories are divided according to the 1-digit level of the ISCO (1968) (see: table 13) (5).

Without doubt: Production and application of CIM which is probably the most important innovative process within the secundary sector will be strengthen the tendency of "tertiarization".

6. Conclusions

Occupation-by-sector-matrices are - despite some methodological limits - useful instruments in order to investigate technology induced employment effects. Labor matrices can be understand as a linkage between the micro- and macroeconomic investigation level.

There is no doubt that the metalworking industry is the typical sector for CIM application. Different opinions may be exist concerning the occupational groups which are influenced by this technology . On the supposition that the occupational groups described above are mainly affected by CIM application the labor force potential influenced by this technology amounts approximately to 5...11 per cent which seems to be not to much. In Future on the macroeconomic level the changes within the occupational structures seems to be more important than replacement effects.

Changes in the occupational structures are caused by a cluster of influencing factors. Among these the technological progress plays an important role. But it would be wrong to trace back the changes in the occupational structures of the different sectors to technological progress solely.

On the one hand the computed internationally comparable occupation-by-sector matrices allow a very detailed insight into the occupational structure within the economic sectors and their development. On the other hand the bulk of data makes difficult to generalize the tendencies of development. An useful approach to recognize the tendencies of development seems to be the tree-sector-theory. There is no doubt that the CIM technology will be strengthen the tendency of "tertiarization" within the society.

Footnotes

(1) The terms "occupation-by-sector matrix" and "labor matrix" are used synonymely below.

(2) A very comprehensive study giving internationally comparable labor matrices was done by Zymelman /52,53/. The data base of this study refer to the years 1970/72.

(3) These problems are discussed in more detail in /3,5,6/.

(4) Due to data availibility unfortunately the figures of the different countries refer to different time points. However, the tendencies of development can be recognized from the following tables.
The computation procedure for elaborating the internationally

comparable labor matrices was partly so difficult that certain differences between the figures presented in this paper and data published in official sources or in other paper can not be excluded. Some problems concerning these differences was discussed in more detail in /5/.

(5) In the literature the definition of the primary, secondary and tertiary sector is not consistent. But there is widely an agreement that the primary sector contains the sectors agrigulture, forstry, and fishery. The secondary sector includes the sectors producing goods. The tertiary sector includes all other sectors.
To some extent the occupational categories given in the ISCO classification may be classified in "primary occupations" (ISCO-code 6), "secondary occupations" (ISCO-code 7) and "tertiary occupations" (all other major occupational groups) (see: tables 14 and 15).

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Table 1 Use of means of work in the FRG in the years 1965/86 by degrees of mechanisation and automation in per cent /45/

Degree of mechanization/ automation	Means of work	share of employed persons (%)
high (computer-controlled machines/plants)	e.g. NC/CNC machine industrial robot, display, computer-controlled medical devices, PCs	7.1
advanced (semiautomated machines/plants)	e.g. automated lathe, punch with automatic feed	4.7
medium (manually controlled machines/plants)	e.g. lathe, milling mach., copying machines, accounting machine	21.1
low (driven tools)	e.g. hand drill, type writer	14.2
none (simple tools)	e.g. file, brush, spade, hammer, microscope	52.9

Table 2 Use of programm-controlled means of work in % /45/

means of work	field of application	main use		temporary use		degree of spread	
		1979	1985	1979	1985	1979	1985
program and computer-controlled machines/plants	manufacturing	0.9	0.5	1.5	0.7	2.4	1.2
large process systems	process engineering	1.5	0.8	1.5	1.7	3.0	2.5
computer-controlled medical devises	medicine	0.3	0.2	0.7	0.5	1.0	0.7
computer, data-proc., terminal, display	data-proces-	1.7	4.5	3.0	11.0	4.7	15.5
"Modern office articles"	office	1.3	1.2	3.1	4.2	4.4	5.4
All "program-controlled means of work"	total	5.7	7.2	8.8	18.1	15.5	25.3

Table 3 Influential factors on the composition of occupations and qualification (following /31/)

Group of factors	Influencial factors
scientific-technical progress	e.g. development of technology; development of means of work; development of products; new materials;
organizing conditions of work	e.g. international, national, local and enterprise division of labor; firm size
change of number of employes persons and mobility	e.g. demographic structure of employees persons; migration and fluctuation of employed persons
objectives of educational and social policy	e.g. contents of education; aims and level of general education; level of vocational training; employment of woman;
socio-economic targets	e.g. full-time employment
conditions for effecting vocational training	e.g. subjective preconditions for efficiency, work task

Table 4 Structure of the manufacturing industry (ISIC 1968)

31	Manufacture of food, beverages and tobacco
32	Textile, wearing apparel and leather industries
33	Manufacture of wood and wood products, including furniture
34	Manufacture of paper and paper products, printing and publishing
35	Manufacture of chemicals and chemical, pertoleum, coal, rubber, and plastic products
36	Manufacture of non-metallic mineral products, except products of petroleum and coal
37	Basic metal products
38	Manufacture of fabricated metal products, machinery and equipment
39	Other manufacturing industries

Table 5 The shares of the different manufacturing sectors on the total number of employees

country	year	manufacturing sector									
		31	32	33	34	35	36	37	38	39	total
FRG	1950	3.84	7.31	2.83	1.24	1.95	0.55	2.83	8.94	0.26	29.76
	1961	3.95	6.09	2.29	1.78	2.99	0.75	3.81	14.33	0.34	36.32
	1970	3.67	4.93	2.06	1.92	3.86	0.72	3.41	17.43	0.32	38.33
	1982	3.34	3.00	1.96	1.95	3.66	1.15	4.29	13.94	0.28	33.55
Sweden	1970	2.49	2.51	2.59	3.49	1.92	1.19	2.03	11.67	0.35	28.24
	1980	2.04	1.27	2.16	3.10	1.79	0.79	1.61	10.66	0.21	23.95
Finland	1980	2.79	3.29	3.14	3.88	1.90	0.97	0.88	7.58	0.30	24.73
Austria	1971	3.97	5.62	2.73	2.07	2.44	1.57	2.21	10.60	0.20	31.41
	1981	3.63	4.07	2.97	1.99	2.51	1.32	2.05	11.60	0.25	30.39
Netherlands	1985	3.22	1.08	0.74	2.23	2.43	0.67	7.57		1.35	19.29
U.S.A.	1984	1.74	2.20	1.14	2.12	2.08	0.61	0.89	8.76	0.40	19.94

Table 6 Occupational groups considered in the analysis

ISCO	
0-1,0-2,0-3	Physical scientists, architects, engineers and related technicians
7-2	Metal processers
8-3	Blacksmiths, toolmakers and machine-tool operators
8-4	Machinery fitters, machine assemblers and precision instrument makers
8-5	Electronical fitters and related electrical and electronics workers
8-7	Plumbers, welders, sheet metal and structural metal preparers and erectors
9-7	Material-handling and related equipment operators, dockers and freight handlers

Table 7 The shares of selected occupational groups within the total number of employees (in %)

		occupational groups (ISCO 1968)	
		0-1,0-2,0-3	7-2,8-3,8-4, 8-5,8-7,9-7
Finland	(1980)	4.59	13.74
U.S.A.	(1984)	3.21	11.55
Netherlands	(1985)	4.14	11.43
FRG	(1950)	1.82	14.07
	(1961)	3.18	17.00
	(1970)	4.67	18.69
	(1982)	5.58	15.00
Sweden	(1970)	6.81	16.17
	(1980)	8.86	14.58
Austria	(1971)	2.77	14.63
	(1981)	3.19	15.54

Table 8 The share of the relevant occupational groups on the total number of employees in the manufacturing sectors

country	year	occupational group (ISCO 1968)		
		0-1,0-2,0-3	7-2,8-3,8-4 8-5,8-7,9-7	total
FRG	1950	2.9	32.3	35.2
	1961	4.7	36.2	40.9
	1970	6.9	36.6	43.5
	1982	8.9	29.8	38.7
Sweden	1970	11.3	35.6	46.9
	1980	13.2	36.3	49.5
Austria	1971	4.3	32.1	36.4
	1981	4.9	33.7	38.6
Netherlands	1985	6.9	30.5	37.4
Finland	1980	7.7	27.4	35.1
U.S.A.	1984	6.8	29.9	36.7

Table 9 The shares of the manufacturing sectors on the total number of employees of these occupational groups

country	year	occupational group (ISCO 1968)	
		0-1,0-2,0-3	7-2,8-3,8-4 8-5,8-7,9-7
FRG	1950	47.7	65.7
	1961	53.4	75.7
	1970	56.8	73.4
	1982	53.6	66.7
Sweden	1970	48.7	62.1
	1980	46.2	60.1
Austria	1971	48.7	68.9
	1981	47.0	66.0
Netherlands	1985	32.3	51.4
Finland	1980	41.4	53.7
U.S.A.	1984	42.3	50.2

Table 10 The share of the relevant occupational groups on the total number of employees in the metalworking sectors

country	year	occupational group (ISCO 1968)		
		0-1,0-2,0-3	7-2,8-3,8-4 8-5,8-7,9-7	total
FRG	1950	5.0	71.4	76.4
	1961	7.0	64.4	71.4
	1970	8.1	59.2	68.3
	1982	11.9	47.5	59.4
Sweden	1970	15.0	58.9	73.9
	1980	17.0	56.1	73.1
Austria	1971	7.1	62.6	69.7
	1981	7.6	59.4	67.0
Netherlands	1985	10.5	53.5	64.0
Finland	1980	11.7	59.2	70.9
U.S.A.	1984	11.0	36.1	47.1

Table 11 The shares of the metalworking sectors on the total number of employees of these occupational groups

country	year	occupational group (ISCO 1968)	
		0-1,0-2,0-3	7-2,8-3,8-4 8-5,8-7,9-7
FRG	1950	32.4	57.4
	1961	38.9	67.2
	1970	40.7	66.7
	1982	38.1	57.9
Sweden	1970	30.2	48.9
	1980	31.2	50.4
Austria	1971	33.0	54.7
	1981	32.7	52.3
Netherlands	1985	19.1	35.4
Finland	1980	21.5	38.7
U.S.A.	1984	33.0	30.1

Table 12 Employment structure in different countries /9/ (1)

	1970	1985	1970	1985	1970	1985
FRG	8.6	5.5	49.3	41.0	42.1	53.5
France	13.9	7.6	39.6	32.0	46.5	60.4
Italy	20.3	11.2	39.7	33.6	40.0	55.2
U.K.	3.2	2.6	44.8	32.4	52.0	65.0
Netherlands	7.2	4.9	38.6	28.1	54.2	67.0
Belgium	4.7	2.9	43.2	29.7	52.1	67.4
U.S.A.	4.5	3.1	34.3	28.0	61.2	68.9
Japan	17.5	8.8	35.6	34.8	46.9	56.3
Kanada	7.6	5.2	30.9	25.5	61.5	69.3
Austria	18.9	9.0	40.4	38.1	40.8	52.9
Switzerland	8.6	6.6	48.1	37.7	43.3	55.7
Sweden	8.1	4.8	38.3	29.9	53.6	65.3
GDR	12.8	10.8	51.2	50.7	36.0	38.5

(1) The figures for the GDR were computed by the author.

Table 13 Classification of the major groups of occupations (ISCO 1968)

Major group	Titles
0/1	Professional, Technical and Related Workers
2	Administrative and Managerial Workers
3	Clerical and Related Workers
4	Sales Workers
5	Service Workers
6	Agricultural, Animal Husbandry and Forestry Workers, Fishermen and Hunters
7/8/9	Production and Related Workers, Transport Equipment Operators and Labourers
X	Workers Not Classifiable by Occupation

Table 14. Distribution of employees by occupation

country	sector	year	6	7/8/9	3	4	5	0/1	2
1	2	3	4	5	6	7	8	9	10
FRG	Primary sector	1950	99.6	0.3	0.1				
		1961	99.2	0.4	0.2	0.1	0.1		
		1970	97.5	1.4	0.2	0.4	0.3	0.1	0.1
		1982	93.7	2.7	1.4	0.7	0.4	0.6	0.5
	Secondary sector	1950	0.1	86.3	5.9	0.9	1.3	3.5	2.0
		1961	0.1	83.4	5.3	2.1	1.8	5.3	2.0
		1970	0.2	74.0	11.3	3.2	1.8	8.0	1.5
		1982	0.1	65.9	15.1	4.0	2.0	9.8	3.1
	Tertiary sector	1950	0.5	30.6	16.1	16.9	19.1	13.6	3.2
		1961	0.7	23.8	18.5	20.6	18.1	14.3	4.0
		1970	0.7	19.3	20.9	19.9	17.9	17.5	3.8
		1982	0.7	14.7	25.9	13.8	20.3	20.1	4.5
Sweden	Primary sector	1970	95.8	1.1	0.8	0.1	0.2	0.8	0.2
		1980	90.5	4.1	1.7	0.6	0.9	1.8	0.4
	Secondary sector	1970	0.1	71.9	8.3	2.4	2.2	13.4	1.7
		1980	0.6	65.0	10.3	3.0	2.4	16.9	1.8
	Tertiary sector	1970	0.2	17.0	19.2	14.8	19.2	26.6	3.0
		1980	0.5	15.0	18.0	11.5	18.9	33.0	3.1
Austria	Primary sector	1971	98.2	0.8	0.3	0.1	0.5	0.1	
		1981	96.8	1.4	0.7	0.2	0.4	0.4	0.1
	Secondary sector	1971	0.1	78.1	10.6	2.7	2.4	5.7	0.4
		1981	0.3	74.8	10.8	4.1	2.5	6.2	1.3
	Tertiary sector	1971	0.4	16.1	25.4	17.1	25.1	14.8	1.1
		1981	0.7	16.4	24.4	15.9	23.1	17.7	1.8
Netherland	Primary sector	1985	94.4	1.8	1.5	0.5	0.3	0.7	0.8
	Secondary sector	1985	0.9	65.6	11.7	4.1	1.8	10.1	5.8
	Tertiary sector	1985	0.3	14.8	23.3	13.9	17.3	27.9	2.5
Finland	Primary sector	1980	96.2	1.5	0.6	0.2	0.2	1.2	0.1
	Secondary sector	1980	0.5	72.7	8.2	2.6	3.5	10.2	2.3
	Tertiary sector	1980	1.0	18.1	21.2	13.3	20.6	23.8	2.0
U.S.A.	Primary sector	1984	79.6	8.7	4.0	0.9	1.0	3.9	1.9
	Secondary sector	1984	0.2	66.7	12.4	2.9	1.8	9.2	6.8
	Tertiary sector	1984	0.6	14.1	25.5	9.6	19.9	22.4	7.9

Table 15 Sectoral and occupational structure of employees

			Occupational group (ISCO 1968)							
country	sector	year	6	7/8/9	3	4	5	0/1	2	Total
1	2	3	4	5	6	7	8	9	10	11
FRG	Primary sector	1950	99.0	0.1	0.3	0.0	0.1	0.1	0.3	22.1
		1961	97.8	0.1	0.2	0.1	0.1		0.2	13.5
		1970	94.8	0.2	0.1	0.3	0.3	0.1	0.3	7.6
		1982	92.5	0.4	0.4	0.4	0.2	0.2	0.7	5.1
	Secondary sector	1950	0.2	77.0	30.2	6.2	7.3	23.5	42.5	42.4
		1961	0.3	80.8	25.5	10.7	10.7	31.0	37.9	48.2
		1970	1.4	80.9	37.6	15.3	9.8	33.8	29.9	48.8
		1982	0.8	78 .5	32.3	19.1	7.6	28.8	36.2	43.1
	Tertiary sector	1950	0.8	22.9	69.5	93.7	92.6	76.4	57.2	35.5
		1961	1.9	19.1	74.3	89.2	89.2	69.0	61.9	38.3
		1970	3.8	18.9	62.3	84.4	89.9	66.1	69.8	43.6
		1982	6.7	21.1	67.3	80.5	92.2	71.0	63.1	52.0
Sweden	Primary sector	1970	98.4	0.3	0.5	0.1	0.1	0.3	0.7	7.9
		1980	90.8	0.8	0.6	0.4	0.4	0.4	0.8	5.6
	Secondary sector	1970	0.6	75.3	23.9	10.7	7.7	36.8	28.8	38.8
		1980	3.4	69.1	23.0	12.3	6.2	21.2	23.3	32.6
	Tertiary sector	1970	1.0	24.4	75.6	89.2	92.2	72.9	70.5	53.3
		1980	5.8	30.2	76.4	87.3	93.4	78.4	75.9	61.8
Austria	Primary sector	1971	98.3	0.3	0.3	0.1	0.6	0.2	0.4	14.0
		1981	94.5	0.3	0.4	0.2	0.3	0.3	0.3	8.5
	Secondary sector	1971	0.5	82.5	29.0	13.3	8.5	27.6	28.8	42.7
		1981	1.5	78.5	26.3	17.3	8.0	22.2	36.8	41.0
	Tertiary sector	1971	1.2	17.2	70.7	86.5	90.9	72.2	70.8	43.3
		1981	4.0	21.2	73.3	82.5	91.7	77.5	62.9	50.5
Netherlan	Primary sector	1985	91.2	0.3	0.4	0.3	0.1	0.2	1.3	5.2
	Secondary sector	1985	4.6	64.9	17.4	10.9	4.3	13.1	49.2	28.1
	Tertiary sector	1985	4.2	34.8	82.2	88.2	95.6	86.7	49.6	66.7
Finland	Primary sector	1980	94.4	0.6	0.5	0.3	0.2	1.0	0.7	12.9
	Secondary sector	1980	1.4	71.7	20.0	11.1	9.8	21.3	42.2	34.1
	Tertiary sector	1980	4.2	27.7	79.5	88.6	90.0	77.7	57.1	53.0
U.S.A.	Primary sector	1984	74.2	0.5	0.3	0.2	0.1	0.4	0.4	1.8
	Secondary sector	1984	3.2	63.1	15.0	10.0	3.1	13.1	23.9	26.3
	Tertiary sector	1984	22.6	36.4	84.7	89.8	96.8	86.5	75.7	71.9

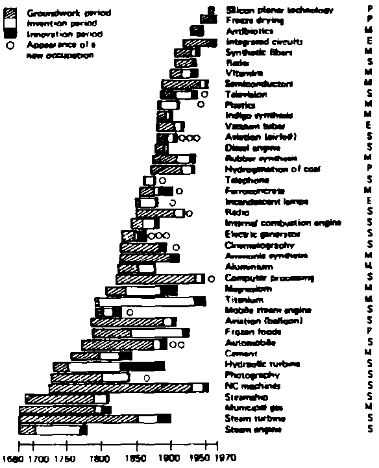

FIGURE 1 · Innovations and new occupations. E, element invention; M, material invention; P, process invention; S, system invention. Source: Dierkes et al. (1977).

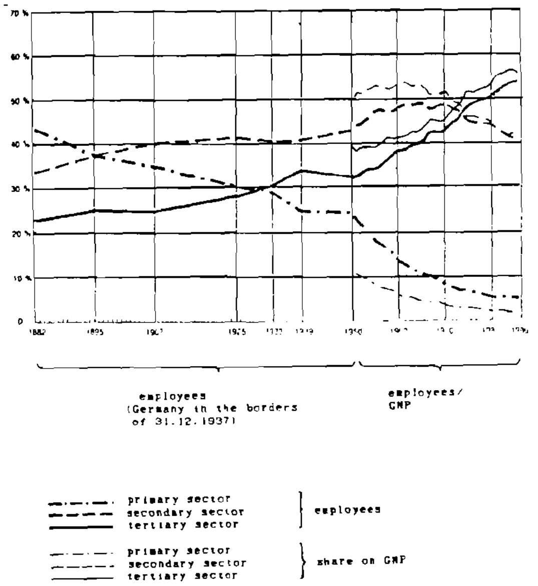

Figure 2 Development of the sectoral shares on the total number of employees and the sectoral shares on GNP in the FRG /9/

Logistics of Computer Integrated Manufacturing

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LOGISTICS OF COMPUTER INTEGRATED MANUFACTURING

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1. INTRODUCTION

Manufacturing and logistics activities are highly interrelated and interdependent. In this interaction, manufacturing plays the dominant role, since only what has been produced can be stored, handled and transported. Correspondingly, the developments in manufacturing have always been accompanied by adequate changes in logistics activities. On the other hand, the state of development of logistics is a prerequisite and a catalyzer for manufacturing improvements. Due to these natural interrelations, the implementation of Computer Integrated Manufacturing (CIM) technologies is expected to have a major impact on logistics. These impacts and their social and economic consequences have to be anticipated in advance and the implications for management and policy making drawn.

In its broader understanding, logistics comprises all those activities which are necessary for overcoming disparities of temporal, spatial and quantitative nature, ranging from the procurement of materials, their processing and finishing within the factory itself, through to the distribution of finished products to the customer. These activities incorporate the planning, implementation and monitoring of transport, handling and storage activities as well as the information flow necessary for these operations. From the perspective of the national economy as a whole, the logistics activities are carried out both by specialized sectors (logistics or logistics related sectors such as: freight transport, wholesale and retail sales, communication), as well as by the production and non-production sectors. The function of logistics is to link the distribution network, the manufacturing process and the procurement activity in such a way that customers are serviced at high level and yet at lower cost. In this respect, logistics can be viewed as a prerequisite and a continuation of the manufacturing process in the supply and the distribution spheres, since from the wider economic perspective the production process is actually completed when the product reaches its customer.

As it will be shown in this paper, there are enough reasons and evidence to believe that under the influence of CIM the role, the structure and the organization of the logistics activity will radically change in the near future. It may be also expected that these changes will exercise a reverse impact on CIM.

The importance of this analysis is emphasized by the fact that logistics activities constitute a good deal of the economic activity of a nation. Different studies reveal a similar magnitude of logistics activity in the various countries. Thus, in terms of costs, logistics activities amount to 20-30 % of the total national expenditure. In relation to the Gross Domestic Product (GDP) it was estimated that logistics costs account to 21.2 % in the USA (A.T.Kearney ltd., 1984), 20.3 % in Sweden (Agren, 1983), 19.5 % in France [1980], 22.0 % in the United Kingdom (McKinnon, 1989), 26.1 % in Bulgaria . A study carried out by A.T.Kearney (Kearney, 1986) covering 500 companies in Europe showed that logistics costs constitute from 8 to 22 per cent of the value of sales of the investigated companies, depending on the sector of the economy in which the companies operate.

Logistics activities provide employment to 20-30 % of the working population of the industrialized nations. Our estimates, based on internationally comparable labor matrices, indicate that logistics activities provide employment to 20-30 % of the working population of the industrialized nations: 23.13 % in Austria, 20.25 % in Finland, 20.6 % in FRG, 22.2 in the Netherlands, 20.5 % in Sweden, 30.7 % in the USA. The trend in most of the investigated countries is towards an increase of those employed in logistics in the economy.

The problem of analyzing manufacturing-logistics interaction, in the context of CIM, has not been sufficiently addressed in the literature. The lack of theories and models as well as examples of such analysis made it necessary to concentrate on developing hypothesis of the major impacts of CIM on logistics, supported as much as possible by hard facts and representative cross-country data, rather than making in-depth elaborate analysis to derive quantitative dependencies or developing advanced theories. The focus is on both micro and macroeconomic level.

2. CIM IMPACTS ON COMPANIES LOGISTICS

To compete successfully in today's marketplace requires total co-operation and co-ordination of all activities. The current situation in most of the markets, characterized by fast changing demand for high quality customized products, short product life-cycles, increased complexity of economic links (due to product complexity and product diversification), severe competition and raised standards for customer service, requires short lead-times (production, delivery, including the time for designing new products). In such conditions, CIM appears to be a powerful technological tool in achieving economies of scope.

The introduction of CIM technologies and especially Flexible Manufacturing Systems (FMS) contributes to the growth of production flexibility and the ability of the manufacturing systems to respond quickly to fluctuations in demand. CIM contributes to higher market performance of the system by assuring high standard quality and increased production flexibility (by shortening lead times, decreasing production lots (batch sizes) increasing product assortment, etc). The implementation of CIM leads to entire reconfiguration of the in-plant logistics system, as a consequence of the installation of automated storage and transportation systems, capable of storing and handling any variety of parts in the required sequence. This, in turn, results in dramatic reduction of the unproductive components of the manufacturing lead time and contributes to the flexibility of the manufacturing system. IIASA's FMS data bank as well as other studies provide considerable evidence in this respect. The analysis of IIASA's FMS data bank shows that the implementation of an FMS reduces the lead time (the time from order to delivery) on average by a factor of four in comparison with conventional technology. Simultaneously product assortment is increased and production lots are decreased [Tchijov, 1989].

On the other hand, many experts and adopting firms seem aware that in order to make use of the increased production flexibility the whole material flow system (including the supply and the distribution stages) should be flexible (Ranta, Wandel, 1988), (de Vaan, 1989). Apparently, it is no use employing flexible production (through CIM) to manufacture products that will sit for weeks in the distribution network, or that will require mountains of input inventories to compensate for an inflexible supply system. In other words, the successful implementation of CIM requires flexible supply and distribution systems. There are signs that management consciousness of the importance of logistics for the successful implementation of CIM is growing fast. The great reduction of raw materials and finished goods inventories (on average by a factor of 2.8), reported in IIASA's FMS data bank, indicate that the successful installers of FMS are exploiting flexible logistics systems. The fact that the more recent FMS report higher value of inventory reduction than the older ones, would suggest that logistics considerations are becoming of increasing importance and are a pertinant element of FMS implementation strategy. A number of case studies and surveys (Shapiro and Haskett, 1985), (Mortimer, 1986 and 1988), (Voss, 1987), (Jansen and Warnecke, 1988) also show that the successful adopters of CIM (and FMS in particular) have either made the required changes in their supply and distribution systems (usually through implementing the Just-in-time concept) to match the requirements of CIM or have made use of existing flexible supply and distribution systems, based on long term collaborative relations with fewer subcontractors, vendors and customers. They also indicate that this has become a conventional approach of the leading Japanese and Western companies. The competitive advantage of the Japanese firms to a great extent can be explained by the far better synchronization of their manufacturing and logistics systems (Schonberger, 1982).

Common managerial and technological strategies are being applied in accomplishing this. The most popular and quickly spreading is the Just-In-Time philosophy. According to this only what is needed (in amount and quality) is produced, transported, distributed etc. JIT philosophy is supported by a wide range of physical improvements (changing plant lay-out, cutting set-up times etc.) and socio-managerial rationalizations (introducing Total Quality Control (TQC), creating flexible work force, close co-operation with vendors and customers) aimed at increasing the flexibility and the responsiveness of the whole manufacturing logistics chain [Hutchins, 1988], [Lubben, 1988]. The Manufacturing Resource Planning (MRP) system have been developed and modified into Distribution Resource Planning (DRP) system to serve the needs of the management of the distribution processes.

These common managerial strategies along with market pressures and the greater awareness of the potential for productivity growth, are providing an impetus to the uniform development of manufacturing and logistics. It is quite obvious that in the efficient harmonization of manufacturing and logistics activities there is a great potential for accelerated and competitive development. It is also very often the case, that the introduction of CIM in one company triggers developments not only in its logistics system, but forces increased flexibility in its suppliers (eventually implementation of CIM) and is a prerequisite for implementation of CIM by the buyer-companies.

3. MACROECONOMIC IMPACTS OF CIM ON LOGISTICS

From the various possible aspects of analysis of the macroeconomic impacts of CIM on logistics the analysis is focused on the following components of the logistics system: a) distribution patterns; b) transportation; c) inventories; d) logistics labor. These components of the logistics system are expected to feel the major impacts of CIM implementation.

3.1 CIM Impacts on Distribution Patterns

The literature and the supporting data are providing many examples and supporting data on the growing diversity and complexity of products and shortening of the product life cycles (see for example Yamashina and Masumoto 1989, Mortimer 1988 Ayress 1987, 1989). The growing product complexity and diversification along with the Fordist-type (highly specialized and large scale) production have contributed to the increased complexity of the intracompany economic links and the growing trend of vertical integration. It is typical for a big manufacturing company nowadays, exploiting economies of scale, to maintain a large network of suppliers, vendors and subcontractors.

The introduction of CIM gives the possibility to manufacture economically a greater variety of products in small volumes, closer to the raw materials or/and consumer markets. Since the potential of large scale production for productivity increase have been largely exploited so far, in order to increase productivity and competitiveness with CIM, more and more companies will turn to small scale customer oriented production. This, in turn, will lead to the wide spread of small scale manufacturing outlets capable of producing a great variety of products according to customer orders and situated closer to the raw materials or/and consumer markets. This may result in completely different territorial distribution of production and will contribute to a trend away from vertical integration. The implications of this phenomenon for the distribution patterns, as well as for the other elements of the logistics system, are quite remarkable.

In the first place, the logistics (the supply and distribution) chains will be shortened and a number of intermediaries in the flow of goods will be eliminated. Statistical data and studies already indicate an overall trend of decline of wholesaling. The business is contracting as a consequence of the absorbtion of their logistical functions by producers and/or multiple retailers. A comparison of the structures of the UK consumer goods marketing channels in 1938 and 1983 revealed that the flow of consumer goods (by value), which was passing through the wholesalers had decreased from 47 % in 1938 to 36 % in 1983 (McKinnon, 1989). However, there exist large differences among countries and trades, regarding the role of the wholesalers. Author's estimates of the participation of the wholesale sphere in the flow of goods in the economy (measured by the wholesale sales/manufacturing output ratio) of nine industrialized countries in the years around 1985 showed a similar magnitude of the role of wholesaling in most of the investigated countries - the USA, FRG, UK, Sweden, Finland and Austria - the wholesale sales/manufacturing output ratio is between 0.6 - 0.8. The lowest wholesale sales/manufacturing output ratio is manifested by Canada (0.38), while the participation of the wholesale sector in the goods flows in Denmark (1.15) and especially Japan (1.71) is much higher.

The difference between countries, in respect to the role of the wholesale sphere, determines the scope of the possible influence of the restructuring of the distribution patterns as a result of the wider application of CIM. In this respect, the case of Japan deserves special attention. Surprisingly enough, the leading country in the implementation of new manufacturing and logistics technologies has a very complicated multi-layer distribution system. However, recent studies indicate that this system is in the process of reconfiguration and many producers have turned to developing their own highly flexible distribution system (Yamashina and Masumoto, 1989). Despite national differences, the application of CIM on a broad scale will contribute to the declining role of the wholesalers in the economy, which will be associated with corresponding economic and social impacts. At the same time, it may quite well be the case that some of them may find a new niche as organizers of new types of partnerships and distribution networks.

Secondly, the application of CIM is a factor facilitating re-organization of the intra firm's economic links and relationships. CIM will increase the shift from multiple to single sourcing, from competitive to long-term co-operative intra-firm relations. New forms of intracompany relations, (the so called 'Value added partnership') based on the intensive use of advanced communication and information technologies (Electronic Data Interchange) are emerging and quickly spreading (Johnston and Lawrence, 1988).

3.2 CIM Impacts on Transportation

The transportation system is one of the logistics areas which will experience major impacts of the broader application of CIM. Developments in the transportation sphere have contributed to the fast development of manufacturing and made it possible and economic for manufacturing to penetrate and exploit territories which are situated far from the raw materials and/or consumer goods markets. At the same time the transportation system has always experienced the extensive impact of manufacturing, since one of the major demands for transportation services comes from the manufacturing sector.

The analysis of the evolution of the transport systems for a number of countries shows a general shift towards faster and more reliable transport. During the last several decades dramatic changes have taken place in transportation systems. One example of these dramatic changes is the shift in the transport modal split. The demand for fast, punctual and reliable transport has triggered the enormous development of road transport in place of rail transport. Correspondingly, dramatic changes in the transport infrastructure have taken place. This trend is accompanied by a number of technological innovations in all modes of transport resulting in decisive increase in their speed and loading capacity. Among the most important common trends for all the countries are: a) faster growth of GDP than the transport work (in tkm); b) similar modal split changes, especially for the high value goods (the shift from rail to road and air transport); c) fast development of combined transport and integration with production and trade (the emergence of the so called 'production-transport chains); d) unification of the transport, packaging and loading-unloading equipment; e) changes in the criteria for evaluation of the transport performance from 'price' and 'cost' towards quality, punctuality, flexibility, reliability, minimization of goods damages and losses.

The implementation of CIM on a broad scale will give further impetus to these general trends. From one side, CIM will contribute to a further decrease of transport work (in tkm) due to the closeness of manufacturing to the raw materials and/or consumer markets. On the other side, as argued earlier, CIM requires flexible and reliable supply and distribution systems, which will give an impetus to a further shift towards the more reliable and flexible transport modes - road and air. This, in turn, may result in increased share of the transportation costs in the value of the goods. An example of this phenomenon is the case of Japan. Author's estimates, based on Input /Output tables showed that for a ten year period 1970-1980 the transportation services purchased by each machinery sector (the sectors belonging to ISIC 38) have visibly grown in relation to the sectors output.

3.3 CIM Impact on Inventories

The impact of CIM on inventories is one of the strongest and most visible impacts on logistics. In the first place, CIM affects directly inventories in the adopting firms and sectors. The implementation of CIM results in a number of significant improvements contributing to inventory reductions. The dramatic set-up time reduction and the entire reconfiguration of the in-plant logistics system lead to dramatic reduction of the in-process waiting time and work-in-progress, respectively. The buffer stock component of work-in-progress is drastically reduced due to decreased uncertainty in the production process. CIM assures standard quality of production which reduces the scrap and rework, resulting in less works in progress. The flexible production system, as a rule is complemented by flexible supply and distribution systems which in turn reduces the raw materials and finished goods inventories. According to IIASA's FMS data bank, the typical inventory reduction (both raw materials and finished goods and works-in-progress) as a result of FMS implementation is in the range of 25 - 75% (or by factors of 1.5 - 4). In about half of the observed Flexible Manufacturing systems inventories (both indicators) were reduced by a factor of two. Analysis of IIASA's FMS data bank shows a trend of increasing reduction of inventories over time (e.g the more recent systems cause higher inventory reduction than the earlier ones (Tchijov, 1989). This evidence suggests that the direct CIM impact on inventories is expected to grow in the future.

Secondly, as a result of increased production flexibility and short production lead times, CIM allows working to customer's orders not to stock. This could have a chain impact on the input inventories of the customers of the CIM manufacturer. Due to the fact that the sizes of inventories along the material flow are interdependent, reduced finished goods inventories at producers (through small batches and lead times) reduces the cycle and the buffer inventories (the safety stock) at customers. Similarly, CIM could trigger increased flexibility in the subcontracting and supplying network and thus reduce their inventories. Unfortunately, there is not sufficient data to definitely prove this statement. However, the existing data regarding Finnish case studies indicate that FMS has triggered the introduction of JIT supply and distribution systems. The result was almost a 100% reduction of raw materials and finished goods inventories and a corresponding reduction of suppliers' and customers' inventories. As argued earlier, CIM will induce changes in the distribution patterns, the result of which will be further decline of the role of the wholesalers, and reduction of their inventories. The inventories held by the wholesale sector constitutes a good deal of the total inventory stock in the economy - 32 % in Japan, 22 % in the USA, 20 % in Sweden, 23 % in the UK (as of 1983-1984). Similarly, the production to customer orders, along with the fast and reliable distribution system will decrease inventories in the retail sector. The changes in transportation system, facilitated by the implementation of CIM (the reduction of transportation distance and the growing demand for high speed, reliable and punctual transport, the shift from rail to road etc.) will also strongly contribute to inventory reduction. This would imply that a great portion of CIM impact on inventories goes far beyond the firms and the sectors implementing CIM - in the suppliers and the customers (upstream and downstream of the logistics chain).

Looking for possible influences of the introduction of CIM on inventories on a sectoral level, an analysis has been carried out using IIASA's data base on inventories, compiled on the basis of the United Nations Industrial Statistics as well as contributions from collaborators from various countries. This data base covers 15 countries with different economic systems and size over a period of 10-20 years. The sample is limited to those countries for which reasonably harmonized data could be obtained. The data is structured according to the 3-digit level of the International Standard Industrial Classification (ISIC) of All Economic Activities [ISIC 1968]. For each of the investigated country data was collected for about 25 ISIC sectors of the manufacturing industry. This data base provides broad analytical possibilities. For the purposes of identifying the inventory impacts of CIM the analysis is restricted to the manufacturing sector as a whole, as well as the sectors of the machining industries (ISIC 38): Metal Products (ISIC 381), Machinery n.e.c. (ISIC 382), Electrical Machinery (ISIC 383), Transport Equipment (ISIC 384) and Motor Vehicles (ISIC 3843). These are the sectors which are reported to be implementing more intensively the new manufacturing and logistics technologies. The value added inventory ratio as well as estimates for the days of stockholding have been used as measures for inventory productivity.

The analysis revealed quite similar trends in inventory/value added ratio in the different industries. The typical trend is represented in Figure 1.

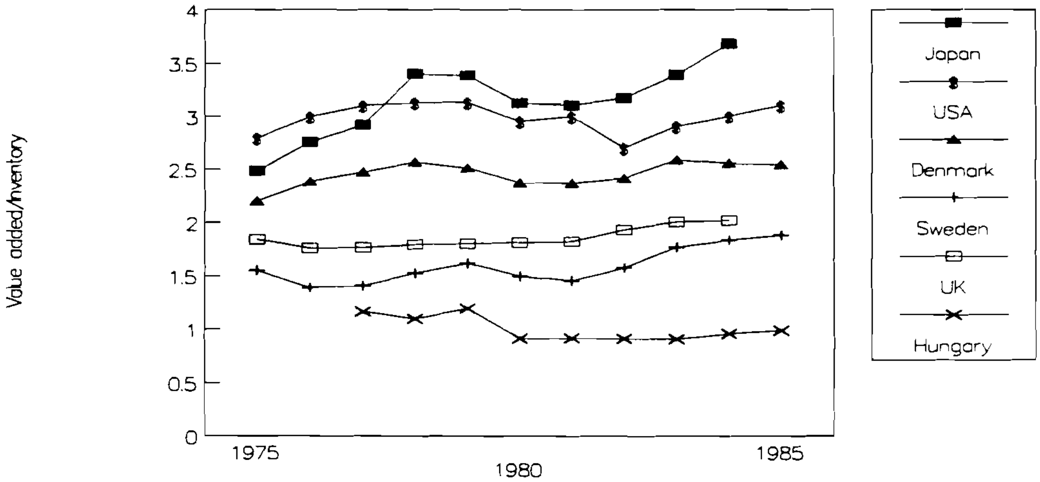

Figure 1. Value added/inventory ratio in Manufacturing (ISIC 3).

Despite cyclical variations, in most of the Western countries there is a trend of improvement of the inventory/value added ratio. The upward trend in the value added/inventory ratio, especially during the last years of the investigated period, may be partially attributed to the developments in manufacturing and logistics. Similarly, the gaps between Japan and the USA, between them and the rest of the countries, between the western and the Eastern countries can also be partially attributed to that. Ceteris paribus, the implementation of CIM should lead to observable upstream trends in the value added/inventory ratio. However, the data does not show such a clear trend. One reason for that is that the current rate of CIM application can not lead to measurable changes in inventory level at sectoral level. When interpreting the inventory trends in the context of the macro inventory impacts of CIM, the numerous contradictory factors that influence inventory levels should also be taken into consideration. An extended list of these factors and their analysis on country and international data is presented in (Dimitrov, 1984 and Chikan et. al.,1986). In most cases the influence of these factors can be so big that their effect on stocks can offset the impacts of CIM.

The magnitude of the potential benefits from inventory reduction as a result of CIM (assuming equal penetration rates) varies considerably among countries and sectors depending on the current inventory levels. The analysis of the value added/inventory ratio as well as inventories in terms of days of stockholding (Figure 2.) reveals the existence of stable differences between the different countries. This is true for the whole manufacturing industry as well as for the different manufacturing sectors. Japan is leading as a rule followed by the USA, the greater part of the West European countries and Canada, the Scandinavian countries and Austria and the East European countries.

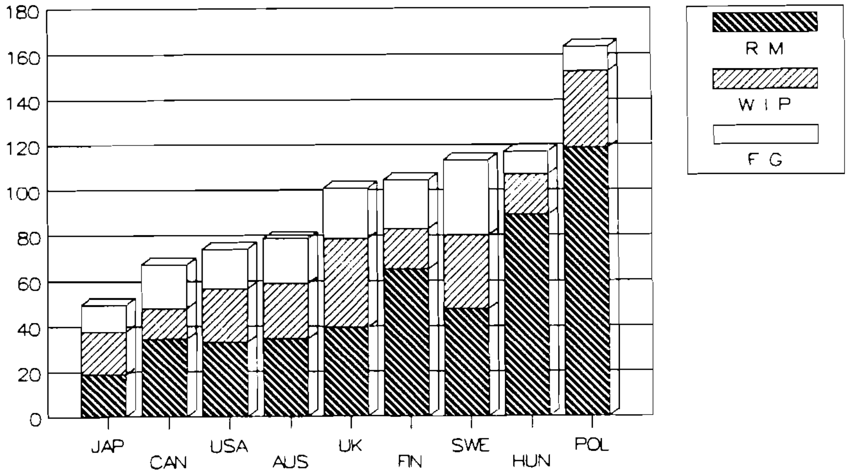

Figure 2. Inventory in days in Manufacturing industry (ISIC 3) for 1980 -1985.

Depending on the penetration rates and current inventory levels, the benefits of inventory reduction, as a result of

CIM implementation, could be enormous for the adopting firms, sectors and the economy as a whole. First of all, inventory reduction means released financial resources (capital) which can be used for self-financing of CIM projects or other capital investments. A full application of CIM in the Non-electrical machinery (ISIC 382), and the associated reduction of inventories by only a factor of two (note that the average inventory reduction due to FMS, without the extreme cases, is by a factor of 2.8) will release financial resources equal to from 2.5 (in the case of Japan) to 10 (in the case of Hungary) years of investment in machinery and equipment in the different countries (under the current inventory levels and rates of investment in machinery and equipment in the respective countries) (see Figure 3). The situation is quite similar if the other manufacturing sectors are considered. Thus, the released inventories as a result of 50 % inventory reduction in the Transport equipment (ISIC 384) industry is equal to 1.8 years of investment in machinery and equipment in Japan, 3 years - in the USA and Sweden, 3.5 years - in Austria, 4 years - in Canada, 6 years - in UK, 6.5 years - in Hungary, 7.5 years - in Finland. More than 90 % of the existing FMS are installed in these two sectors.

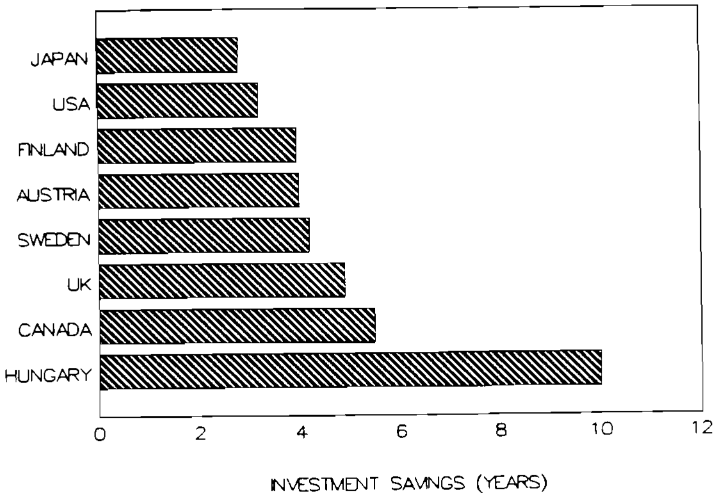

Figure 3.Potential investment savings in Non-Electrical Machinery (ISIC 382) due to 50 % inventory reduction.

On the other hand, inventory holding costs constitute a great deal of the production costs, since maintaining inventories carries with it the costs of storage, material handling, obsolescence, etc., as well as interest payments. Their reduction is an important source for increasing production efficiency. The data presented in Table 1 illustrates the potential of inventory reduction for production cost reduction in the machinery industries (ISIC 38) in four countries.

Table 1. Inventory Holding Costs* in per cent of Value Added

ISIC	Japan (1984)	Finland (1984)	UK (1984)	USA (1985)
381	6.3	13.7	14.7	9.9
382	11.1	15.5	16.6	12.0
383	7.6	15.8	15.1	10.4
3843	4.2	13.7	16.6	6.0

* Inventory holding costs are assumed to be 30 % of the value of stocks.
Source: UN Industrial Statistics Yearbook

From the various economic benefits of FMS, personnel reduction is most often cited to be competing with inventory reduction. A study of FMS implementation in small to medium sized firms in the UK (Haywood, 1986), comparing the relative magnitudes of inventory and personnel reduction, resulted in the conclusion that inventory reduction seems to be one of the major driving forces for FMS implementation in the investigated companies. Our analysis on IIASA's FMS data bank (Dimitrov 1989) entirely supported that finding. The results of the comparative analysis of the relation between pay-back time and inventory reduction and personnel reduction showed that FMS pay-back time is much stronger correlated to work-in-progress reduction (r = -0.714) and raw materials and finished goods inventory reduction (r = - 0.564) than with personnel reduction (R = -0.410).
These facts would suggest that inventory reduction, in particular, and logistics considerations, in general, are of growing importance for the successful implementation of FMS.

3.4 CIM Impacts on Logistics Labor

The wider application of CIM will exercise a major impact on those employed in logistics. Author's estimates based on the internationally comparable occupation by-sector labor matrixes, prepared by H-U. Brautzsch for the CIM Project (Brautzsch, 1988) showed that those employed in logistics activities in the machinery industries (ISIC 38) occupy in Austria 15.5 % of the total number of employees of the industry in question, in Finland - 10.7 %, in FRG -8.9 %, in the Netherlands -14.8 %, in Sweden - 11. 9 %, in the USA - 11.7 %. The implementation of CIM technologies and FMS in particular exercises great impact on one of the major logistics occupation category (group) - material handling and related equipment operators (ISCO 9-7). The data from IIASA's FMS data bank shows that personnel reduction due to FMS is approximately a factor of four. A good deal of these personnel are related to logistics - warehousing, transportation and materials handling e.g. belonging to the above mentioned occupational group. This occupational group constitute 41.4% of logistics labor in the production sectors in Austria (1981), 39.8% in the Netherlands (1985), 48 % in Sweden

(1980), 47.45% in Finland (1980), 28.8 % in the USA (1984), 22.4 % in the FRG (1982). Nicol and Hollier (Nicol and Hollier, 1985) have found that the workforce employed in materials handling (including the number of persons employed full-time on handling, storage and transport duties, as well as the estimated number and commitment of those who include handling as part of their duties) constitute 12 % of the companie's total works labor costs (33 UK companies investigated).

In the context of the discussion on CIM impacts on distribution patterns e. g. the declining role of the wholesale sector, the changes in the transport modal split - the decline of railways in freight transport, and on inventories - their drastic reduction, it has to be expected that the broader application of CIM technologies will cause visible labor impacts in the transportation and the trade sectors as well as on the occupational groups related to warehousing, handling and in-plant transportation in all sectors of the economy.

4. CONCLUSIONS

The introduction of technologies on a broad scale will mean fundamental change both in the organizations implementing these technologies, and in the economy as a whole. Undoubtedly, logistics is one of the economic spheres that will be strongly affected by CIM. The major impacts of CIM on logistics, as they can be seen now, consist in: a) entire reconfiguration of the in-plant logistics system; b) creation of highly flexible supply and distribution networks based on long-term collaborative intra-firm relations, associated with declining (or new) role of the intermediaries; c) fast growth of high quality transportation services at the expense of a decreased amount of transportation work; d) drastic reduction of inventories in the companies and sectors, implementing CIM, as well as in the buyer and supplier companies and sectors in wholesaling and retailing; e) labor force shifts related to the outlined impacts. The magnitude of these impacts will depend on the penetration rates of the CIM technologies.

At the same time, logistics will exercise reverse impacts on CIM. Along with the traditional impacts, logistics can facilitate the fast development of CIM by providing the frame work of future computer integration beyond the boundaries of the factory. The first steps in this respect have already been undertaken by the emergance of the so called 'Value Added Networks' (VANS).

The dynamics of the development of CIM and logistics technologies requires constant monitoring with the goal of early identification of the emerging new trends and possible impacts.

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National Differences in the Business Environment for Automated Manufacturing

by

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The new generation of automated manufacturing technologies have far-reaching implications for the competitive positions and international structuring of industrial enterprises and national economies. The rate of introduction of AMT, and the degree of success in managing AMT systems, are a function of relative astuteness in managing industrial enterprises and of the national environments in which these enterprises operate. The introduction of AMT into factory systems is part of the ongoing process of adaptation to economic and technological change. Factory automation holds great promise for giant leaps forward in productivity and in response time to changes in market demands, but it also poses deep problems of adaptation to change for individuals, enterprise organizations and societies at large. These implications and some alternative paths to resolving some of the inevitable dilemmas are outlined in what follows.

Comparisons Between U.S.-Japanese Business Strategies

There are significant differences between the manufacturing strategies of U.S. 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 preoccuppied 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 U.S. 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]. U.S. and European firm have been relying more heavily upon mergers and acquisitions to shore up their competitive manufacturing capabilities; they are also pre-occuppied 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 necessiate 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 pre-occuppied 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 marketplace. 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 marketplace. 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 individualizm 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.

West Germany Experience [ICMA]

German 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 German (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, dut to short supply of personnel. Personnel procured externally often are in conflict with their countractor 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: Decision 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 countrol 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 Coordination: Production automation requires specialists working in segmented areas and management of overlapping tasks, which in turn have to be properly corrdinated and integrated.

6. Process design and organization to include man-machine-computer relations:
    (a) The rigidity of computer-aided systems demands a flexible attitude toward computer application and the unavoidable constraints of organized efforts.
    (b) The logic of the computer is not adequate to the logic of man. Hence the need for understanding the reactions and behavior of colleagues. Also information must be given free of "computer chinese".
    (c) 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.
    (d) 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 avaiable 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 downtime due to technical reasons, differentiating between scheduled and unanticipated downtime. 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, German automated equipment manufacturers have adopted the following policies and strategies:

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

    Germans have a very high regard for technik 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 results 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, German 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 Germans keep 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 U.S., 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 U.S. and the U.S.S.R.). Other characteristics of the Soviet "command economy" that have retarded the rate of diffusion of automation technology in the U.S.S.R. 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 [BIALER: 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 U.S.S.R. 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 marketplace.

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 U.S.S.R., 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 downtime 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 piecemeal and not only requires a restructuring of whole segments of the production 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 severly 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 coordinated, equipment that has not been pre-tested for factory operation, and ancilliary 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 it needs (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 words 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 U.S.S.R. 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 Enteprise 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 coordination among functional units and reallocaition 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&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&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 satellities will need to locate where transportation and communication networks provide 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 Western 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 coordination 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 become 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 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 percent 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 Western 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 the profiles on General Motors and General Electric demonstrate), and therefore government, financial structures, and government relations play on 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 deterents to enterprise willingness to introduce factory innovation and impliment it effectively. In some respects, the environmental conditions prevailing in the United States and most of the Western European countries are the exact opposite of what characterizes the Japanese business environment, where "vision and censensus" 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 1960's, American firm in the consumer electronic and automative 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 pentrating overseas markets through the marketing, production and technology complimentarities 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 U.S. and most Western 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 give 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 implimentation 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 system. 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 automatin.

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 that 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 percent of what they need to know to function within the industrial enterprise [OHMAE]. In the United States, the impression is that most American firms expect that all new employees will have at least 80 percent 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 viewpoint is generally inimical to the inherent characteristic of the new factory automation systems that rely heavily upon individual responsiblity for total quality control and just-in-time systems [WSJ-EXA].

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Socio-Technical CIM Trajectories in National Systems of Innovation: The Need for an Interdisciplinary Approach

by

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ABSTRACT

The subject of this paper is the influence of national systems of innovation on the technical and organizational features that make up computer integrated manufacturing (CIM) trajectories. It is argued that in order to adequately explain the rate and direction of CIM trajectories, the investigations of innovation theory could usefully draw on the insights of recent developments in industrial relations systems theory. Particular attention is paid to the investigation by German researchers of the social dimensions of the supply side of the economy within 'national patterns of skill formation'. In conclusion, it is emphasized that the understanding of national systems of innovation and the direction of CIM would greatly benefit from further communication and collaboration between the innovation and industrial relations systems communities.

THE TECHNICAL AND ORGANISATIONAL FEATURES OF CIM

The Technical Features of CIM

There is presently a worldwide trend within contemporary manufacturing towards 'systemofacture'[1] through increasing the technological and organizational integration of production processes. .At the technical level this is made possible and inspired by the declining cost and increasing miniaturisation of microelectronics. Within manufacturing processes this has taken the form of the development and diffusion of microelectronic based control and monitoring equipment, and the establishment of low cost interactive communication and feedback networks. Microelectronics based developments have thus provided the foundation for extending the automation of manufacturing transfer and transformation equipment into (i) the *control* of this equipment, and (ii) the closer technical *integration* of *manufacturing with design and planning* processes, and *producer firms with customers and suppliers*

The result has been the incremental introduction of computer integrated manufacturing (CIM) systems in the sense of computer based systems in **design** (computer aided draughting and design, computer aided engineering etc.), **planning** (shop floor control systems, manufacturing resources planning, computer aided process planning etc.), **manufacture** (computer numerically controlled machines, robots and automatic guided vehicles, flexible manufacturing systems, factory data acquisition etc.), and the **integration** of these spheres of operation (computer aided design and manufacture, computer aided design and production planning etc.) Yet, as frequently commented, the degree and level of CIM diffusion is often exaggerated. Moreover, there are substantial variations in the rate and direction of diffusion in firms of different sizes, in different industrial sectors, and in different countries. In the research of Edquist and his colleagues, for example, significant sectoral and national differences have been found in both the relative proportion of microelectronics based product innovation and process innovations in flexible automation, and the relative diffusion of different elements of process automation.[2]

The Organizational Features of CIM

These improvements in technical control and integration are being accompanied by new forms of 'internal' and 'external' organizational integration both within manufacturing firms and between these firms and their suppliers and customers. This phenomenon has two sources. Firstly, manufacturers worldwide are being forced to address the success of Japanese organizational techniques integrating direct labour processes, direct/indirect production tasks, departmental structures and strategies, and both producer-supplier and producer-customer/user relationships.[3] Secondly, where integrative CIM systems are introduced to improve production capabilities, the effective implementation of these systems requires a simultaneous increase in *organizational control and integration*. There is now substantial evidence of productivity failings and investment disasters by those firms which have implemented CIM without adequate consideration of the necessary social innovations in training, industrial relations and organizational restructuring for more integrated production systems.[4]

These new forms of integration may take the form of either 'job integration' or 'organizational integration' Three characteristics of CIM technologies enhance the trend towards job integration: their *'defunctionalizing'*; *'multidimensional'* and *'interdependent'* characteristics.i.e.(i) as tasks are taken over by machines, operators task load is reduced and job boundaries are blurred as new direct or indirect production tasks are taken on; (ii) as equipment integrates the tasks of previously separate machines and people, it increases in complexity and cost and requires, for faster throughput and minimum machine downtime, operator roles that transcend traditional craft/process, craft/craft and craft/staff boundaries; and (iii) as system interdependence increases there is greater dependence upon correct data entry, operator/ designer collaboration, and an understanding of system principles in order to deal with anomalies. This requires changes in job boundaries as operators are training in abstract thinking and system principles, to be 'responsible for results', and work in closer collaboration with colleagues[5]

The integrative nature of CIM systems makes it impossible, however, for individual operators to have an in depth knowledge of the whole 'system'. As interdependence increases, new forms of teamwork are therefore increasingly required both within and between the spheres of design, planning and manufacture.. New forms of organizational integration are currently being established varying between more or less permanent or temporary teams and matrix structures designed to facilitate an integrated approach to both product and process innovation.[6] As aptly observed in the 1988 report of the ESPRIT 1199 Data Management Working Group, 'No single individual is able to overview all aspects of manufacture and therefore a leap from the individual to the collective skill must be made. The quality of the CIM-system depends considerably on how this is done. To work on CIM-systems includes develcpment of a new kind of collective skills affecting design work, planning work and shop floor production work.'[7]

Similarly to developments in the technical sphere, however, the extent to which real integration has occurred is variable and often exaggerated. There are substantial variations in the degree to which the 'multi-skilling' of craftworkers represents real interdisciplinary craft training and work tasks.[8] The frequent citations of direct workers taking on 'indirect' tasks often over-emphasizes the degree to which effective decentralization is occurring.[9]. Moreover, while in some firms organizational integration techniques may be preferred because of the degree of specialized knowledge required (by legislative or technical requirements), in others it merely represents the opposition to job integration through organizational divisions perpetuated by internal political forces.[10] As discussed in a recent study of CAD/CAM, the form and degree of job/organizational integration varies between countries depending on the size of firms and their 'design profiles'.[11]

The Significance of Variations in Technical and Organizational Integration

In this context the dominant focus of innovation policy research has been on the level of technical development and diffusion of CIM, the obstructions to this development caused by inappropriate institutional frameworks, and the policies required in order to speed up the introduction of CIM. The most sophisticated exposition of the theoretical underpinnings of much of this research has been provided by Christopher Freeman and Carlotta Perez. Their focus on the emergence of 'techno-economic' paradigms within revolutionary periods of technological change isolates the important role played by 'new technology systems' in both promoting the technical side of CIM and creating a new 'technical common sense' amongst managers and engineers. From this perspective, the heart of the contemporary 'technological revolution' is provided by the set of radical and incremental innovations driven by the declining cost, increasing capabilities and pervasive application of the new 'key factor' of production: microelectronics.

This approach specifically emphasizes the importance of the 'institutional framework' of change and recognizes the existence of variations in both levels of CIM and sectoral or national institutional frameworks. However, in its extreme form, the significance of these factors is limited to two key features. Firstly, the variations on the general pattern of institutional change are regarded as of less significance than the fulfilment of the institutional imperatives for rapid innovation. Secondly, the key significant feature of institutional variations and levels of CIM, is the degree to which different institutional forms hinder or facilitate the rate of CIM development and diffusion. In this regard this perspective embodies a technicist version of an 'evolutionary-historicist' approach to societal change that has a long standing tradition within the social sciences.[12] It is important to note, however, that **this does not necessarily undermine the validity or usefulness of this approach.** Facile debates over 'technological determinism', with all its attendant qualifications and re-qualifications, will not help us in improving the range and depth of our grip on contemporary changes. . What the approach does do, however, is to impose a particular perspective on contemporary technological and socio-economic change that focuses on specific explanatory elements and provides restricted 'criteria of significance' for assessing variations in the pattern and consequences of these changes.

Within the work of both Freeman and Perez, however, there are elements of another approach to CIM development and diffusion. This involves more than their realistic emphasis on the variability of diffusion levels, applications and institutional frameworks in different firms, industries and countries. It is, rather, embodied in three features of their work that place a particular *interpretation* on these variations.. Firstly, they appropriately characterize new production systems as primarily socio-technical rather than technical systems, embodying a 'new trend towards merging all activities - managerial and productive, white and blue collar, design and marketing, economic and technological - into one single interactive system'[13](The explicit intention is to emphasize 'the systemic, feedback nature' of the organizational 'software' as well as the hardware as the 'essential distinguishing feature' of the new firm. Secondly, they attribute an important autonomous role to Japanese organizational techniques in shaping the character of the resulting system of production which they refer to as 'systemation'. This is clearly apparent in their discussion of the 'parallel and even antecedent change' of Japanese organization to the microelectronics revolution, and the 'origins' of the present system as lying in both microelectronics and the Japanese 'flexible organizational' model[14] Thirdly, they acknowledge major variations in not only the institutional framework of the change to systemofacture, but also the techno-economic character of systemation itself. This is most apparent in their discussion of the dual centralizing and decentralizing character of the new systems, a 'contradictory imperative' that makes the final character of CIM systems fundamentally ambiguous. In Perez' words, 'the new paradigm combines trends towards centralization and decentralization, towards more control and more autonomy, so the variety of combinations is likely to be quite wide, not only in the present transitional period, but probably into the future upswing.'([15]

These elements in the work of Freeman and Perez represent a partial and implicit recognition of an alternative approach to variations in technical and organizational integration. This involves an appreciation of two factors: firstly, the major significance of not only the *level* of technical CIM development and diffusion but also the different *directions* and *forms* of socio-technical CIM trajectories; and, secondly, the dynamic effect of different organizational structures and processes in shaping alternative socio-technical CIM trajectories in different institutional contexts In combination, these two factors provide the basis for what can be called the 'socio-technical CIM approach'.

The Socio-Technical CIM Approach

The tradition of socio-technical *thought* was established in the 1950s at the Tavistock Institute in Great Britain, and has been characterized by three key elements: firstly, the importance of examining both technical and human features in understanding work systems; secondly, the existence of alternative forms of social organization around the same technology; and, thirdly, the role of job designers in creating socio-technical systems that fully exploit the possibilities for job enrichment and group work. In recent years this tradition has been expanded in two crucial ways: firstly, socio-technical job design has been extended to the design of technical hardware and software to support job enrichment and group work;[16] and, secondly, there has been an extension of scope to examine the manner in which broader production cultures and institutional structures 'load' socio-technical options for or against 'humane' job design.[17] The socio-technical CIM approach, as defined here, combines these two theoretical developments in examining the institutional structures and patterns shaping the direction of both the technical and organizational features of socio-technical CIM trajectories in a manner that both enables and constrains job design and system design opportunities

This approach embodies a number of key assumptions in regard to CIM. First, it is argued that CIM can only be usefully defined in terms of both the technical and organizational aspects of integration within 'socio-technical' systems.. As Tom Martin, chairman of the IFAC Committee on the Social Effects of Automation, remarks 'computer integrated manufacturing...is not a matter of integrating the computer into manufacturing; what needs to be integrated are the flows of materials and information, and this is where computers interconnected by means of coupled data links can perform useful services. Consequently, one had better call this "computer aided integrated production."[18]'. In an important sense, therefore, the social and technical features of CIM cannot be isolated as separate 'components' of socio-technical CIM systems. They are, rather, the performance of system functions or tasks through the use of an inherently interdependent and interdefined set of technical and human factors of production. This has led some system designers to advocate the use of the term 'task integrated production'.(TIP)[19] In this manner meaningful definitions and characterizations of CIM systems include the nature and allocation of material and information flow and control tasks to individuals or groups at particular hierarchical levels and/or within specific functional departments in the organization.[20]

Secondly, the socio-technical CIM approach assumes the ever present possibility of '*functional equivalence*' i.e. that there are 'functional equivalents' in both the technical means for achieving operational goals and the organizational requirements of these technical means. As a result there is no clear 'one best way' of organizing socio-technical production systems[21] , rather there may be socio-technical trajectories of incremental technical and organizational innovation that are either functionally equivalent in terms of achieving system objectives or cannot be effectively accepted or rejected through technical or market 'tests'.

Thirdly, this approach adopts a '*successful adaptation through modification*' assumption i.e. that the response of firms, sectors or countries to technical changes, models of production success, and new forms of competition is influenced by their embedded 'socio-technical' structures, and these may result in new socio-technical trajectories that create competitively successful new forms of production [22] Moreover, in contrast to 'technocratic' or 'econocratic' arguments that technical efficiency or economic productivity is the only measure of industrial development[23], it is assumed that of equal or greater importance is the socio-political consequences of the alternative socio-technical trajectories and the factors influencing their direction and development.[24]

From the point of view of this approach the variability of both the technical and organizational components of CIM pose important questions for the future direction of socio-technical CIM trajectories. On the one hand organizational variations can combine with 'received' technical CIM elements to create alternative incremental and cumulative CIM trajectories. As observed in numerous studies of firm based technological trajectories, the nature, development, location, rate of introduction and use of different technical components of CIM will *vary* depending upon *organizational strategies* for integrating information and material flows.[25]. Thus, for example, an organizational structure that facilitates greater shop floor autonomy and control, may develop craft oriented shop floor programming, and flexible scheduling and control systems that builds upon rather than undermines this tradition. On the other hand, the rate and direction of past technical CIM development and diffusion can facilitate or hinder the ability of organizational and group processes to structure the new socio-technical systems. Where, for example, CAD/CAM and MRP/CAPP systems have been introduced, and the computer power is located primarily in the design and planning offices, communication systems have been developed to enable a 'one way' downward flow of information and control, and software is employed that is both complex to use and incorporates detailed planning outputs or NC programming instructions, then the role of manufacturing personnel in the overall production process is greatly undermined. The socio-technical CIM approach extends, however, beyond this examination of detailed interdependence and interaction between social and technical processes of development to include the broader institutional influences that pattern these trajectories, and the economic and political developments that may foster or undermine them

TECHNOLOGICAL TRAJECTORIES, LEARNING PROCESSES AND SOCIO-TECHNICAL CIM

Innovation Theory

The conceptual tools and empirical research of innovation theory provides key insights into the dynamics of socio-technical CIM. This is particularly apparent in the investigation of technological trajectories and product cycles, especially in different sectors or types of firms and in the context of changing patterns of inter-firm relationships Within innovation theory, there is thus a well established set of concepts for identifying and explaining the direction of development of the technical components of CIM. Following a reassessment of Schumpeter's classic work, research in recent years has revealed the evolutionary, incremental and cumulative nature of both technological development and diffusion. Drawing upon post-Kuhnian research on scientific paradigms, writers such as Johnson, Dosi, Nelson and Winter, Constant, Belt and Rip, and Clark have emphasized the central importance in technological development of a *dominant design heuristic* including exemplary achievements and successful search heuristics or exploratory problem solving techniques; a *technological community* that incorporates both a set of expectations about the success of the heuristics and the ethos and practices of the sub-culture; and the punctuation of evolutionary periods of development by *radical or revolutionary breaks* .[26] In regard to CIM components, a sophisticated use of this theory has recently been employed by Hagedoorn in the analysis of the technological trajectories in the process control industry.[27]

A similar emphasis has been placed on the role of technological 'paradigms', 'trajectories', 'regimes', 'corridors' or 'innovation avenues' in the explanation of the evolutionary character of diffusion.[28] A recent application of this approach to the diffusion of CIM has been undertaken by Cainarca, Coombo and Mariotti in their examination of the current stage of innovation diffusion of flexible automation.[29] This process is not merely the passive acceptance of commercially available technologies but involves the *active* selection, adaptation, development and improvement by users, a process that often provides a greater contribution to productivity than the purchase of a generic system. The progress along such trajectories by particular firms involves a substantial degree of site-specific and firm-specific learning ('learning by doing', 'learning by using' etc.), embodied in a variety of incremental and more radical changes in skills, training and organization ('humanware' or 'liveware'), as well as hardware and software. Of key significance can be the interaction between users and suppliers in a 'virtuous circle' of learning that complements more formalized R&D development activities.[30] In recognition of this phenomenon, there have been a variety of attempts in recent years to explicitly improve learning processes through close contact with users or producers, the monitoring of production performance, involvement of workers in process improvement schemes etc.(e.g. just-in-time, total quality control techniques).[31]

The interpretations offered of the major factors influencing the direction of technological trajectories vary considerably. Some innovation theorists stress the central role played by the inherent characteristics of the technology, while others emphasize the key role played by market demands.[32] In the work of Dosi, Pavitt and Archibugi, Cesaratto & Sirilli, however, it is accurately observed that the nature of the innovation process varies across industrial sectors.[33] Dosi also emphasizes, however, that a central role is played by non-market influences on firm motivation and market structure.[34] It is in this area that industrial relations systems theory can play an important explanatory role. From the point of view of the socio-technical CIM approach, innovation theory can be usefully supplemented by incorporating the institutional insights of contemporary 'extended' industrial relations systems theory. The purpose of the next two sections is to provide an illustration of how this can occur through a selective review of some of the key ideas of (i) Andre Sorge and his colleagues on the impact of 'socio-technical traditions' on CNC development and use, and (ii) Wolfgang Streeck and Andre Sorge on the interdependence of product and labour markets within national systems of innovation.

Socio-Technical Traditions and CNC Development and Use

In a series of books and articles throughout the 1980s based on research comparing manufacturing plants in West Germany, Great Britain and France, Arndt Sorge and his colleagues have investigated the influence of national socio-economic conditions on the development and use of computer based process technologies. Similarly to the evolutionary theories of technological innovation and diffusion, they revealed that 'technical effects come about .. by the interaction of technical development and application with economic and social factors; technology therefore has to be considered as being adjusted to economic and social influences to the same extent as it has an impact on economic and social developments.'[35] Their interpretation of how this occurs, however, emphasizes two features: firstly, a 'culturalist' assumption that views 'socio-technical events as *strategically* influenced by tentative, piecemeal experimentation and innovation, under a focus of action which brings *technical*, *organizational* and *labour* considerations to bear on each other.'(p.9)(emphasis added); and, secondly, a 'societal effect' assumption that 'the causes that underlie the continuous adaptation, improvement and modification of technology. may be looked for, in central social and economic tendencies, and not only in the internal dynamics of science and technology as reasonably self-contained areas.'[36]

This general orientation is employed in an investigation of how comparable engineering firms in West Germany and Great Britain have responded differently to the technological trajectory of computer based machine tools As discussed by Sorge et.al., the development of CNC equipment represents an extension of developmental trends in both information technology and machine tools.. In the former area, the miniaturisation of information technology hardware has been fundamental in reducing hardware prices, reducing the vulnerability of data processing equipment to environmental disturbances, the developing of computer networks with 'distributed intelligence', the shifting emphasis of cost reduction strategies from hardware to software, and increasing ease of operation.

In the sphere of machine tools, an evolution is observable from mass production 'copy' milling or turning (involving a mechanical sensor guiding a machine that 'copies' a premade part) and small batch 'pegboard' machines (using 'inserted' pegs to guide the machine's operations), record playback (where the machine is led by an operator through the motions for producing the first part), to various forms of digitally controlled NC (Numerical Control) machines that have evolved in correspondence with information technology generally to allow programming to occur on the machine in CNC (Computer Numerical Control) machines and the link up of the equipment into iterative information and control networks in DNC systems (Direct Numerical Control) In this process, however, the machine tools have become mechanically more sophisticated with improvements in tools, materials and cutting mechanisms, in comparison control system price increases have declined in significance compared to overall machine costs. In combination, these trends have enhanced the potential for small and medium sized firms to introduce CNC equipment, and for the equipment to be used in a wider range of products and batch sizes.

An understanding of the development and application of CNC machines within engineering firms must be seen in the context of general changes in production and economic conditions. These provide the production system 'problems' or 'reverse salients' that guide the development and use of CNC equipment on the shop floor. Some of these, as outlined by Sorge et.al., are: the increasing age of machinery, batches of products that are decreasing in size and increasing in variability, a greater attempt to produce modular parts that can be assembled to make more complex parts or differently dimensioned with little difficulty on NC equipment, the increasing accuracy and complexity of machined parts in order to ease and speed up assembly, and changing factory layouts utilising group technology techniques and improvements in shop floor data acquisition to assist in the reduction of inventories, improved throughput time, and achievement of delivery dates. In the face of increased competitiveness from newly industrialized countries and Japanese manufacturing techniques, these conditions represent 'more flexible production, geared to more exacting requirements with regard to design and precision, and subject to tighter control. CNC development and application has responded to such challenges, and has helped to bring them forth.'[37]

Yet in the face of these similar developments in information technology, machine tools and production conditions, the research of Sorge et.al. shows that the reaction of firms differ in different national contexts, shaped by 'unchanging socio-technical traditions'. These result in a national patterning of firms' responses along, what we shall call in this paper, different 'socio-technical trajectories'. For Sorge et.al these are primarily defined by the specific configuration of technical, organizational and labour developments that make up a firm's production systems. A key feature of the differences between socio-technical trajectories of CNC use and development in West German and Great Britain proved to be the the degree to which 'indirect' production functions (including work planning, programming, machine setting, quality control, maintenance, technical design and development etc.) were allocated to shop floor personnel involved in 'direct' production. Particular emphasis was placed upon the location of programming between the planning/ programming department, foremen/supervisors, setters and operators, with West German firms having a substantially greater degree of devolution of programming responsibilities.

This phenomena was related by Sorge et.al. to the different organizational and labour conditions in West Germany and Great Britain. Labour conditions relate to the recruitment, training, retraining, remuneration, and general treatment of labour, but Sorge et.al. emphasize the central role of the education and training system broadly defined to include less formal ongoing workplace learning or 'acquisition of competence' In West Germany this is characterized by a 'pervasive practical professionalism' i.e. apprenticeship is more widespread as the main source of entry into working life, and includes examination and certification in both academic and practical skills; a larger number of workers have more than one apprenticeship, and emphasis is placed on apprenticeship as training for independence, reliability, and commitment even when the job of qualified people changes; semi-skilled workers are trained to perform a greater variety of jobs, and, as is the case for skilled workers, they have a greater possibility for upgrading through formalized retraining during their working lives; many technical courses, lower level engineering qualifications and all Meister qualifications.require prior apprenticeship training; the training of Meisters involves not only a high level of technical skill and experience, assumed to be more than skilled workers under their supervision, but also more training in 'managerial' functions; and engineers have a comparatively strong practical orientation to both their professional training and status, and the 'lower' engineering qualification (Dipl.Ing. or Dipl.Inform) coming out of the Fachhochschule is often preferred by small firms because of their practical orientation and less 'careerist' ambitions; and, finally, management often possesses a greater degree of technical or engineering qualifications, with an especially high proportion of apprenticeship qualifications.

These labour conditions interact closely with and strongly influence organizational structures and processes, and for Sorge et.al. are primarily determined by them.. In West Germany, the organizational hierarchy from the foremen or Meister upwards is more highly technically based, with less functional division between line management and specialists; the ratio of technical support staff to shop floor workers is relatively low, with the largest proportion of works personnel and the lowest percentage of supervisors as a percentage of works employees; in general there is only one level of staff supervision (Meister) compared to two in Great Britain and France; there is less departmental differentiation or fragmentation, and formal organizational charts or structures are more personalized and in general less formalized; and plant control by industrial firms is more technical and production oriented rather than finance based.. It is not surprising, therefore, that operators tend to operate more flexibly across jobs, and tend to have greater autonomy. For example, work plans and time allowances are challenged more often in Germany by supervisors, work groups and foremen tend to be given a greater role in planning, and foremen in Germany are freer to detail workers to particular jobs during a shift as specialist departments tend to detail work less precisely.

The result of this analysis provided by Sorge et.al. was to show the manner in which the West German national systems of education and training influenced the development of organizational structures and processes which, in turn, influenced the use of CNC technologies. However, despite their statement that they are examining the forces influencing 'the continuous adaptation, improvement and modification of technology', their work stops short of showing how the incremental modification and development of CNC technologies is influenced by and combines with organizational and labour conditions to form significantly different socio-technical trajectories. They discuss, for example, the increasing simplicity of computer-user interfaces, and the use of dialogue based programming languages, but this is not extended into an analysis of the form and extent to which a specific software/hardware trajectory may be developed and diffused in a German context that gives greater programming to skilled craft workers and involves an innovation system that includes close relationships between Fraunhofer and other engineering institutes, machine tool producers and technologically sophisticated user firms.. This matter has been addressed, for example, in the development, with the assistance of the German Research and Technology Ministry's Program Fertigungstechik, of 'workshop oriented programming' methods.[38]

In addition, it could be further examined how the comparatively high autonomy of German works personnel and the Meister in scheduling and planning work methods, impacts back upon the development of appropriate production planning and shop floor control systems. There are, for example, at least four different commercially available German computer based production planning systems to support more decentralized forms of production planning.[39] Moreover, in West Germany there is increasing interest in extending shop floor programming, scheduling and work planning into the establishment of relatively autonomous production islands (Fertigungsinsels) that develop upon the principles of group technology and autonomous work groups to the manufacture or assembly of whole groups of products.[40] As observed in detailed studies of technological changes in this area in Germany, the technical support for decentralized group production work requires extensive and detailed development of machine tools and dies, maintenance 'tool kits', computer assisted programming and planning software, data entry facilities and techniques, development of data bases etc. In this area the trend of industrial relations systems research towards an examination of such developments presents the basis for a fruitful interaction with the greater theoretical and empirical depth of innovation theory in this area.

SYSTEMOFACTURE AND NATIONAL SYSTEMS OF INNOVATION

Systemofacture and Alternative Forms of CIM

At a suitably general level of description it is possible to characterize contemporary manufacturing firms as moving towards socio-technical CIM systems or systemofacture through the increasing technical and organizational integration of production. As discussed earlier this is constituted by new communication networks and control systems as well as novel forms of job integration, teamwork and organizational integrative mechanisms. At the most fundamental system level, however, the new systemic structures may take significantly different trajectories: building upon the 'automating' and centralizing potential of the new socio-technical systems or the 'informating' and decentralizing capabilities.

At the technical level there is an essential difference between the 'automating' and 'informating' aspects of new technologies. Automation has the capacity to defunctionalize [41]human beings by mechanizing operations and directing these operations through pre-programmed instructions ('automating'). This can lead to the establishment of 'closed loop' systems, subject to central control and manipulation, with operating conditions substantially built into the initial system design. However, automation also has the capacity to simultaneously generate information by representing the operational process in data form and providing ongoing operational data on working processes ('informate') This can be utilized to provide the foundation for 'open loop' systems, continual learning at the local as well as central level, and incremental modification and development.[42] For this and other reasons it is often emphasized contemporary CIM systems possess both 'automating' and 'informating' capabilities, and centralizing and decentralizing potential. As socio-technical CIM systems become more integrated, and information feedback processes are improved, control over production can theoretically come from anywhere in the system. It is this fact that has led different commentators to remark that information technology does not, in itself, lead to either centralization or decentralization of control.

The potential for centralization is, however, increased through the enhanced monitoring and adjustment of production processes tightly coordinated to meet the demands of strategic management. This phenomenon is facilitated by better and easier access to knowledge of operations, the reduction of job mystique with increasing data and formalization of rules in computer systems, the improved capacity for 'real time' monitoring of processes and fast feedback of adjustment commands etc. It is also driven by constant attempts to improve operations through decreasing throughput time, reducing inventories, and tightening production schedules - as well as traditional management 'control' orientations and the philosophy of management consultants such as Ingersoll Engineers.[43] In addition, the more precise co-ordination of 'internal' production processes with both suppliers' deliveries and customer demands, imposes greater demands on the precision and timing of operations.

In opposition to such a trend, however, there is a simultaneous potential for decentralization enhanced by the increasing technical capacity and declining cost of distributed intelligence and two way information and control networks, the inability of integrated CIM systems to function without adequate input and feedback of correct information, the time and knowledge inefficiencies of responding to varying 'local' production conditions through the feedback of data and receipt of instructions from a 'central' source, and the development of incremental innovation through 'learning by doing' processes at the local level.

Most of the general interpretations of the new techno-economic paradigm that inform socio-technical CIM development emphasize that the instability and rapid change of *product markets* combines with the *flexible potential of CIM technologies* to dictate a trend towards more decentralized forms of integration. Thus what could be called *strategic flexibility* is emphasized as firms face shifting product markets, rapid product innovation, and increasing demands for customization, in the context of international currency fluctuations, changes in tariff restrictions, technical changes that assist faster responses to market demands etc. This strategic flexibility is then seen to require what could be described as *operational flexibility* whereby the organizational structure, technological equipment and labour force are organized to adapt to strategic change and further stimulate both process and product innovation as international competition increases.

Diversified Quality Production and National Patterns of Skill Formation

The key theme of both Arndt Sorge and Wolfgang Streeck's research on the West German system of skill formation is, however, that product markets and technological change are not fully determinant in deciding organizational patterns.. As they show convincingly in the case of West Germany, the degree of technological and organizational decentralization and centralization, and accompanying socio-technical trajectories, are fundamentally influenced by *national institutional structures* that load the socio-technical options available. Developing upon Child's emphasis on managerial 'strategic choice' in responding to 'environmental' change, and Bessant's concept of the 'design space' available in system development, Sorge and Streeck emphasize that the crucial determinant of socio-technical change is the strategic approach of firms to the opportunities created by changes in technology and product markets. In their words, 'Managerial product strategies - manufacturing policies -respond to the market but are not determined by it'[44] Current changes in product markets and technology may even be increasing the significance of this area of choice through increasing the degree of both *uncertainty* and *indeterminacy* .

Uncertainty is increased by the inability of marketing departments to safely predict future profitable products in a rapidly changing situation, and while attempts are increasingly made to address product and process changes by integrating industrial relations and organization planning with business strategies, there are fundamental uncertainties in the optimal organization design for integrating these areas and conducting labour relations.[45] Indeterminacy is created by the degree to which active marketing may be able to influence market signals, the range of choice that firms possess over their performance standards, and the fact that firms always have a variety of markets to choose from. In the context of current changes in competition and the flexible reprogrammable capacities of computer based technologies, the range of options facing firms may be increasing. Flexible automation makes it *possible* for large firms to introduce a previously unknown degree of variety and quality into large batch and mass production, and smaller firms to extend the size and range of their smaller batch customized goods.

For Sorge and Streeck this increasingly opens up for exploitation a product strategy arena of 'diversified quality production' involving the high volume production of customized high quality-competitive goods, *but it does not determine which firms will enter such an arena*. Where a choice is made to enter high quality and more customized mass production markets this has, in turn, a definite influence on the development of new production systems. While Sorge and Streeck recognize 'that there is, and has always been, some degree of choice.', where large West German firms have entered into diversified quality production 'the cost-benefit calculations of choice have increasingly been loaded towards a more organic organization with more enriched skills and overlapping work roles'[46] The example discussed above of CNC use and development can, they argue, be extended to a whole pattern of socio-technical organization.

As Streeck argues on the basis of research into the West German auto industry and industrial relations system, the same conditions in West Germany that influence the more decentralized and flexible use of computer based technologies are also influential in deciding which product strategy will be adopted by management (i.e.in the case of the car industry 'diversified quality production'). The high level of shopfloor skills that encourages a decentralized system of production organization, in combination with extensive system of worker's rights and job guarantees in West Germany, has influenced management to search for the kind of markets that would enable them to utilize their comparative skill advantage and avoid the potential problems created by their external labour market rigidities. The strategy to move towards diversified quality production reflects these established institutional structures rather than a product market/technology determinism.

The broader implications of this argument are that only particular types of 'institutionally rich' societies (i.e. those involving extensive institutional support for education and training and developed internal labour markets) are capable of moving into the arena of diversified quality production, and the associated socio-technical CIM trajectory. In addition, unlike Sorge, Streeck places great emphasis on the complex constellation of political actors and institutional interests that support, and can also undermine, such institutional structures. As detailed in a report to the OECD, Streeck reveals that there are features of even the West German political scene that can undermine what may appear in the future to be a rather fragile institutional support for this trajectory.[47]

Process Diffusion in National Systems of Innovation

In this focus on national educational and training institutions and industrial relations systems as a key factor mediating the influence of new technologies and product markets, Sorge and Streeck have emphasized selected components of what innovation theorists such as Lundvall, Freeman, Edquist and Dalum [48] have described as 'national systems of innovation'. In these models, while the importance of education and training and industrial relations systems are fully recognized, the analysis of the causative influences on the direction of innovation is extended into an examination of such factors as the key national industrial complexes, the quality of domestic demand, factor endowments, the system of structure and competition, and the R&D and learning system.

A key emphasis of this work on national systems of innovation is the evolutionary and incremental nature of most learning and innovation patterns. Central importance is attached to routine learning within production, marketing and R&D as a process that both generates problems to be solved by 'searching' organizations (e.g. R&D laboratories) and contributes to their solution. The incremental pattern of such changes within national systems, influenced by the difficulty of establishing trans-national learning systems, leads to the relative stability over time of dominant paths or trajectories within countries, despite conscious national policies to change their direction. Dalum illustrates this most effectively with evidence of the evolutionary trajectories of high technology, medium technology and low technology sectors within individual OECD countries, trajectories which, as measured by their relative position in the nation's economy, are relatively little affected by the varied governmental attempts to promote 'hi-tech' industry

This view of national systems of innovation places central emphasis on a country's 'institutional setup' and 'economic structure', where the former provides the set of formalized rules and non-formalized norms and habits that govern general 'learning' values and practices, and production structures provide the integrated set of user-producer innovation trajectories in a country's leading economic sector or 'development block'. The institutional structure, which includes the national patterns of skill formation described by Sorge and Streeck, are regarded as the 'software' for the 'hardware' of the production structure that together form 'a framework defining the space for interactive learning and affecting its rate and direction.'[49]

In terms of the discussion of socio-technical CIM trajectories, Edquist and Lundvall emphasize the contribution of Swedish firms to the 'grey field combining social innovations with technical innovations (org-ware and human-ware in the language of the IT-epoque'[50]. This, however, is related to a high rate of socio-technical innovation in an institutional framework they define as 'combining Fordism and Standardization with Welfare and Democracy. This institutional framework tends to focus the activities in the system of innovation on process technology.'[51] This is in direct contrast to the discussion by Sorge and Streeck of diversified quality production in the 'large' country of West Germany, with its emphasis on product innovation in shifting product markets as a key feature leading to decentralized socio-technical process innovation.

The central point of Edquist and Lundvall is that the small country status of Sweden (ruling out huge investment and sales efforts in new products), its collective consumption patterns, plus its traditional successes in process diffusion, have led to a very low level of product innovation and diffusion. Yet, it has probably the highest rate of process diffusion as a result of its facilitative institutional framework and economic structure. The significance of the institutional structure is primarily related to the social democratic compromise and an extensive welfare state in a situation of low unemployment that has led to (a) the trade unions' acceptance of technological innovation in a situation of very low unemployment and the strength to insist on labour's share in profits, and (b) employers incentive to build high trust and competence building relations with its workers. Within the economic structure, the dominance of a large firm, export oriented, high R&D engineering 'development block' has strongly promoted the early adoption of advanced technology. The result has been that,

> 'The whole institutional set up, the whole innovation system, seems to have become geared towards one specific model of development (towards the movement along one trajectory) and the ease with which advances have been made in this direction may have weakened the incentives to take on the more difficult task of developing the technological infra-structural basis necessary for radically new product areas.'[52]

The argument of Edquist and Glimmel[53] concerning socio-technical CIM trajectories is that in this context Swedish firms have tended to introduce enlarged jobs and achieve reductions in the vertical division of labour as a key factor associated with the introduction of technology but that this is due to the severe labour shortage in the context of strong trade union organization. These twin factors have led to management attempting to make jobs more interesting in order to reduce absenteeism and turnover, and attract workers. However, this has not been intimately related to major product development and diffusion, nor to the strength of the country's vocational and educational system. Whereas the latter has been emphasized by trade unions for some time, and is now pushed more strongly by management, the former feature may begin to pose serious problems for the 'Swedish Model' in the future if their traditional product markets decline in size and value. Moreover, they emphasize that while the pressures for improved capital rationalization encourage new decentralized forms of technological usage and development, and Sweden can be seen to be progressing along a more decentralized socio-technical CIM trajectory than a number of other countries, there is a substantial degree of management conservatism in Sweden that opposes such decentralization, and trade unions are sharply critical of advances made so far. Despite the presence of exemplary projects, such as that of the Volvo plant at Uddevalla, they pointedly observe that 'its a long way to Uddevalla, even for those working nextdoor.'[54]

CONCLUSION

The integration of the institutionalist studies of industrial relations systems theory with the national systems of innovation research provides a potentially rich and fruitful basis for exploring the direction of alternative socio-technical CIM trajectories. While the national system of innovation studies have usefully explored technological diffusion patterns and introduced a broad range of structural concepts to help explain and differentiate between national patterns, the institutionalist studies have revealed many of the more organizational features of alternative socio-technical trajectories and provided detailed analyses of the interaction between the skills formation and industrial relations systems informed by rigorous comparative methods. From the point of view of the study of socio-technical CIM trajectories, however, the institutionalist studies have paid relatevely little attention to the way in which the organizational components of socio´technical trajectories act upon the incremental development of technology, and the national system of innovation studies have omitted a precise comparative examination of the distinctive organizational conditions characterising national patterns of innovation and in what ways these can be seen to have combined with and influenced process technology development and diffusion in a more or less decentralised direction. In combination, however, these two approaches show signs of beginning to address all these questions.

Once the theoretical ground is opened up for placing the *direction* of *socio*-technical CIM trajectories at the forefront of research, these studies provide an important foundation for the development of both theoretical and empirical research. The multidimensional societal processes affecting these trajectories requires, however, a substantial increase in true interdisciplinary collaboration. At the micro-level, in the immediate area of local socio-technical CIM design, close collaboration between psychologists, ergonomists, industrial engineers and computer specialists is clearly required. In order to co-ordinate these projects with intra-firm structures and innovation processes, the contribution of innovation researchers and industrial sociologists is essential. Most significantly, however, interdisciplinary collaboration is required in the study of national patterns of innovation and political strategies for intervention if the broader context that loads socio-technical options is to be fully considered. This represents a major and exciting challenge for innovation theory.

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[39] (These are: AHP Leitstand DOS system; INFOR CIM Leitstand DOS system; FI2 UNIX system; and Inteps, LPS DOS system. More recently, the LPS system, developed as a production planning aid to production islands, has been extended through the development of a COCOSS system for planning and co-ordinating production islands, and the University of Bremen partners in the ESPRIT 1217 group have produced an IKARUS program that is not yet commercially available

[40] . There are at present approximately 10 major university research institutes, Fraunhofer institutes for applied research and consultancy firms specialising in the establishment of production islands and necessary technological support. See the discussion in R.Badham and B.Schallock, forchcoming, ibid.,

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National Differences in the Approach to Integrated Manufacturing: A Case Study of FMS in the UK and Sweden

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NATIONAL DIFFERENCES IN THE APPROACH TO INTEGRATED MANUFACTURING: A CASE STUDY OF FMS IN THE UK AND SWEDEN

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The use of flexible manufacturing systems tends to vary, dependant not only on differing company size, sector, or region, but also by national policies. Strategies adopted may be consequent upon managerial priorities; the availability of resources - not only financial or technical - but also manpower and skills; and the way in which government, employers and employees interact with one another. This paper discusses just a few of the differences in approach that are generally found in Sweden (where co-determination tends to be the norm), and the United Kingdom (where a more fragmented and confrontational approach is frequently adopted).

Introduction.

Considerable effort has gone into investigating the environment for successful competitive efficiency. In common with most of the English speaking world the U.K has concentrated mainly upon technological change as the most effective way of achieving this. In many companies here this remains the main goal, with relatively little effort being made to adopt the methodological or organisational changes observed in Sweden and Japan. This is despite the fact that many observers internationally have highlighted the importance of such change.

> "There is almost universal agreement about what kind of change is needed. Strengthened participation by all organisation members up and down and sideways on the organisation chart is the factor that can make the difference. Who says so? Drucker, Iacocca, Crosby, Peters, Geneen, Ouchi, Naisbitt, international unions, and the Japanese say so. When a group of such diverse people are in agreement, you have to believe them." (Blake, Mouton & Allen, 1987).

Two French authors (Archier& Serieyx, 1987) agree, and they observe that:

> "The future belongs to those who understand new technologies and the value of informality, to those who anticipate, react swiftly, guarantee high quality and do not drag their feet, to those who mobilise the intelligence and enthusiasm of all employees, to those who build alliances.
>
> The only means of staying ahead in the race is to harness

> the intelligence of men and women who are constantly better educated and better informed, and give them responsibility, more say in the company's decisions; and, in addition, form a network rich and dense in relations with other companies that offer complimentary strengths."

Similarly, an Australian commentator (Ford, 1987), who has studied both Sweden and Japan at close quarters for some considerable time, has - in a consultants report to the Swedish Work Environment Fund - commented upon the fact that Japanese managers are increasingly willing to discuss and reveal the technical side of their production processes. The secret of their competitive success is becoming increasingly embedded in, as he terms it, "Their continual integrated improvements in "Orgware, Humanware, and Social Software'."

At least one Japanese industrialist agreed with this formulation since he has expressed the view that:

> "We are going to win and they (the West), are going to lose. We are beyond the Taylor model. The survival of firms depends on the day-to-day mobilisation of every ounce of intelligence. For us the core of management is precisely this art of mobilising and pulling together the intellectual resources of all employees in the service of the firm. The intelligence of a handful of technocrats is not enough to take up the technological and economic challenges with any real chance of success" (Bessant & Chisholm, 1985).

While the argument is often advanced that Western countries could not, in general, adopt the production policies observed in Japan (entirely ignoring the fact that many Japanese techniques have been derived from the work of Western theorists, such as Deming and Juran (Schonberger, 1982).The same argument could not legitimately be advanced with regard to the UK and Sweden, since the main differences that exist here are those related to inter-personal relations and government policy.

This paper briefly examines a few of these differences in policy and relationships in the light of research carried out on a specific technology, Flexible Manufacturing Systems (FMS). These factors include:

(1) Company Efficiency
(2) Employment, Skills and Education
(3) Organisational Structures: Functional Specialisation, Hierarchies and Strategy.
(4) Buyer-Supplier Relationships.

RESEARCH SAMPLE AND METHODOLOGY.

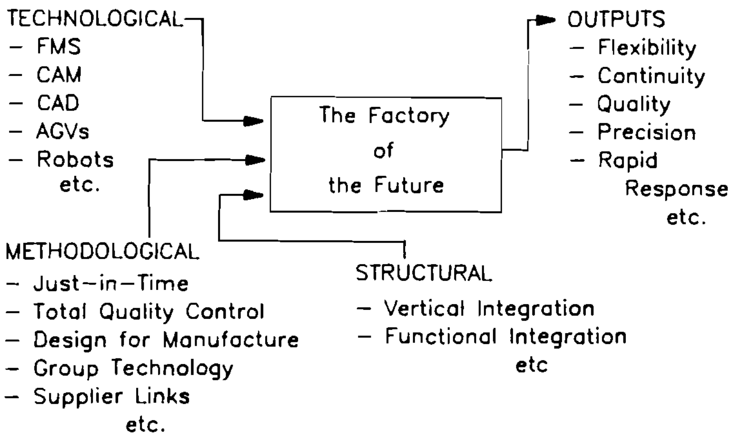
The reseach covered thirteen Swedish companies, ten of whom were users of FMS/FMC and three who were both users and manufacturers of systems elements, eg, machine tools, transfer equipment, (Haywood & Bessant, 1987a).

The U.K sample comprised 41 company interviews. Of these 31 were users and 10 both users and manufacturers (Bessant & Haywood, 1985) and (Haywood & Bessant, 1987b). Further information was obtained from telephone interviews with 27 other user firms.

RESULTS.

Increasing competitive pressures might be met by adapting companies through a whole series of changes in operation which include: the adoption of new technology; changes in the way that the company operates organisationally; and, the breaking down of long established functional specilisations into a more multi-functional approach. One way in which this might be achieved is offered in figure 1.

FIGURE 1. POSSIBLE COMPANY ADAPTIVE CHANGES



Unlike in the U.K, in Sweden the philosophy underlying the use of new technology is heavily dependant on the fact that employers must consult with their labour force with regard to the technology it seeks to introduce. In fact this consultative practice is necessary before the installation of such equipment can begin and involves all aspects of the changing work environment, unlike the U.K where discussions normally follow the installation of equipment and usually only concern pay and staffing levels. The Swedish approach, which is a legal requirement, facilitates a much more institutionalised framework for change which is found to be acceptable to all participants.

Although some managers complained about the constraints this placed upon them, all were of the opinion that it had enabled management and labour to approach the use of new technology without the problems that could be seen in many other countries. The managing director of one company did not even think in terms of differences between workers and managers in the conventional UK sense. To this manager joint consultation was simply logical:

> "In my experience creativity is a function of what people think about their job. If your staff feel happy about their job, the management, the environment and their machines, they will continue with creative thinking - and the company will develop further. My idea is that a company must be developed on the workshop floor - not behind a desk. Creative people stand beside each of the machines, and it is they who can develop the machines by their experience and craftsmanship. Buying equipment and starting to manufacture is only a part of the investment"

(1) COMPANY EFFICIENCY.

As with the U.K in Sweden a wide range of technically and organisationally driven companies are now involved in the implementation of such new technologies as Flexible Manufacturing Systems and Cells. Although there are many similarities that can be observed, there are also interesting differences that may be seen.

Taking turnover per head employed as a measure of productive efficiency in companies in Sweden and comparing this with roughly similarly sized companies in the U.K using FMS/FMC (Haywood & Bessant, 1987a), the level of efficiency of Swedish companies is twice that of the U.K - £69k to £34k. Average company turnover in the sample - at £19m - was approximately fifty percent greater than in the U.K (£13m)

Labour costs in Sweden, as a percentage of total production costs, ranged from 8% to 30%, with an average of 17.8%.

Table 1. Company Labour Costs. (Sweden)

Company.												
(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
24%	n.a	11%	11%	25%	n.a	10%	8%	30%	20%	10%	22%	25%

Average: All Companies = 17.8%
<1000 Employed = 17.5%

The figure for firms employing less than 1000 people was marginally less at 17.5%. These are figures almost exactly in line with recent research on small to medium sized companies in the U.K, where a figure of 18% of total production costs was discovered (Haywood & Bessant, 1987b). Other research suggests that overall in the U.K (including very large firms), a somewhat lower figure is applicable (Goudie & Meaks, 1986) while in the United States it has been suggested that labour costs exceed 10% in only a few industries (Skinner, 1986).

(a) Work in Progress and Stocks Held.

In the Swedish companies visited, the value of WIP and stocks held varied between 5% and 40% of total costs. Overall the average was 21.6%, and amongst firms employing less than 1000 peoplethe average was slightly higher at 23.5%. These figures compare favourably with our sample of U.K firms with less than 1000 employees who held stocks/W.I.P averaging 37% of total costs.

Table 2. Stocks and WIP as a Percentage of Total Costs. (Sweden)

Company.												
(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
N.A	N.A	30%	11%	5%	N.A	40%	7%	N.A	N.A	33%	25%	N.A

Average in Sample = 21.6%
Average <1000 employed = 23.5%

(b) Return on Capital Invested.

In some countries investment in FMS is believed to be strategy based, ie a failure to invest in FMS would mean lack of competitiveness in the mid to long term even though it might not be economically justified at the time of the investment. In Sweden, however, it has to be justifiable and justified. Almost all of the sample firms visited considered that their attitude to investment in new technology was mid to long term and realistic. Only one company of the thirteen considered its investment to be of a "strategic" nature.

The all company average of approximately three years for return on capital was roughly double that of our U.K sample. This in part explains why U.K companies have to resort to calling their investment in relatively expensive systems "strategic" since they find it difficult to justify using "normal" economic criteria as the longer-term thinking of the Swedish companies allow. None of the Swedish companies had a target of obtaining a return on the capital invested in less than two years and usually it was three to four years.

On average the range of target returns usually varied between 29 and 39 months in Sweden, depending on the size of the investment with the latter figure being the average for what was considered heavy investment. None of the companies justified these investments on the basis of reducing labour costs. Labour cost savings were considered to be so small as to be irrelevant since usually labour was redirected to eliminate botlenecks at other stages of production. Sometimes this reallocation of resources was needed to eliminate bottlenecks created by the use of such new technologies as F.M.S.

(2) EMPLOYMENT, SKILLS AND EDUCATION.

In Sweden an impressive acceptance of new technology was displayed by employers and employees alike, and the maintenance of high levels of employment displayed in sample companies.

Overall, employment fell by 221 (or 1.2%), from 1981 to 1986. Over the same time period in a sample of companies in the UK in the small to medium sized company sector of manufacturing engineering (where FMS/FMC had been installed), employment fell by 8% (Haywood& Bessant, 1987a). These smaller firms in the UK can be considered as probably being the ones least likely to lose jobs and therefore taking engineering as a whole, job loss has been dramatically greater in the UK than in Sweden. Job losses in manufacturing - over a slightly longer time period of eight years (1979-87) of 29% has occured (Johnson, 1987). It has been suggested in a study of the Home Appliances Industries (Senker, 1984), and in a study of Conservative economic strategy (Bleaney, 1983), that the heaviest part of this occured in the 1979-81 period as a consequence of the high value of the pound and the subsequent reduction in international competititiveness.

The rationale for the Swedish approach was that a combination of using the latest technologies and the continual, and increasing, upgrading of education and skills would secure greater world market shares. One example of this trend was that while more than 75% of school leavers currently went on to higher education and it was planned that this would exceed 90% by the mid-1990's. It has estimated that only about 30% of UK workers go on to further education (Prais, 1981).

Almost all of the companies in the sample had strong links with the local education system, several exchanging personnel with managers seconded to local schools for up to six months with the teachers they replaced entering employment with the companies for an equivelant period. In several instances it was observed that corporate high schools were being established, for example, by S.K.F and Volvo - now more popular than the state system.

One senior trade union researcher felt that there had been a dramatic increase in the social and political drive towards the integration of technology and people in the mid-1980's, and that managements perceptions were rapidly changing because of the benefits that were accruing from the policy. One manager noted:

> "We underestimated the capability of people originally. Now our approach of utilising the latest technology in conjunction with skilled and adaptable people correctly utilised has led us to exceeding the goals we set.

In terms of the formal educational system in Sweden, children begin - at the age of 13 - to be introduced to, and start to make choices about, their possible full-time occupations. At this age they visit and work within local companies.

(a) Changing Work and Skill Patterns.

With regard to new skills, the consensus was that in Sweden there was an increasing need for people with multiple skills as a result of FMS, but employers in Swedenhave traditionally had policies of upgrading of skills which gave the shopfloor worker the ability to be both horizontaly and vertically mobile within the company. All workers tended to be valued and not placed within categories such as skilled, semi-skilled or unskilled. This approach to the use of labour certainly does not accord with that found in the UK (Atkinson and Meagher, 1986) where it has been observed that:

> "All those firms who had sought it (30 out of 31), had succesfully increased mobility of workers between jobs at similar skill levels.... We noted much less progress in the third area, few firms had achieved functional flexibility vertically over group boundaries"

Company perceptions of labour costsare also quite different in the two countries. While the justification given by user firms for the use of new technologies such as FMS are similar, ie, to reduce stocks and WIP, to increase machine utilisation, to reduce lead times, to reduce labour costs, etc, the suppliers of such systems indicate differences in strategies. In Sweden both user and supplier companies believed that their companies ranked labour costs as only fourth in the list of priorities. However, in the U.K while the users also ranked it fourth, the system suppliers claimed that U.K users were perhaps rationalising their responses to interviewers since to them they almost always stressed that reducing labour costs was the most important consideration.

Swedish companies are generally very pragmatic in their assessment of the use of new technology with almost all of them stressing that such investment had to be strictly "manageable" and not because of some desire to procure the "latest" technology. There were highly developed evaluation practices in place and comprehensive feasibilty studies carried out in these companies.

The Swedish philosophy seems to be summed up by a statement from a representative of one of the largest companies in the sample:

> "We are the company with the widest experience of F.M.S in Sweden, but we do not particularly want unmanned running of such systems since (a) quality may suffer, and, (b) the system will be much more expensive"

In yet another large company the view was expressed that:

> "British systems, it seems to me, depend too much on data collection and manipulation objectives. In Sweden, its much more important to produce parts efficiently and I believe that the ultimate flexibility lies in the human being"

One interesting development commented upon at a number of the companies visited in Sweden was the adoption of higher levels of pay for workers aquiring additional skills, which gave the company greater manpower flexibility. One company adopting a pay structure which placed workers on level one while training, level two on aquiring one machining skill, level three for two machining skills, and so on through five different skill and pay levels. The same philosophy applied to other grades of non-shopfloor workers.

(b) Graduate Employment.

One indicator which can be taken as a measure of skills within the employment structure of companies is that of the level of employees with higher educational qualifications. In many ways this can be a main indicator of the companies commitment to innovativeness in the development of products or processes. The growth of such labour over a period of time may also indicate employers perceptions of the way in which the company can best be developed.

Table 3. Graduates Employed.

	Company.												
1981	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
	5	N.A	N.A	12	1	210	2	1	5	115	N.A	4	N.A
*	1.2	X	X	1.0	3.8	3.0	0.5	0.6	3.6	2.6	X	1.4	X
1986	30	120	1	54	4	1000	5	7	14	200	205	5	N.A
*	7.5	16.5	1.3	5.1	5.9	14.0	0.5	3.5	7.4	5.0	49.0	1.9	X

Note: * denotes the percentage of total employment represented by graduates in that year, for example, in 1986 in company (F), 14% of those employed by the company were graduates.

Even if we exclude those companies for whom figures were not available in 1981 it is clear that with few exceptions there has been major growth in the numbers of graduates employed, with the average for the other nine companies rising from 2.51% in 1981 to an impressive 9.84% in 1986. If we examine the proportion of graduates to all those employed in these 13 sample companies in 1986 we find 1,645 graduates out of a total employment of 18,271 - 9% (Haywood & Bessant, 1987a).

By way of comparison we may note that in a recent study in the UK (Haywood & Bessant, 1987b), the current level of graduate employment in small to medium sized companies was some 2.38%, and that this level had been achieved by only slight growth in the numbers of graduates employed. More importantly, the growth occured because of job losses overall increasing the proportion of graduates - who were normally retained - to all employees.

Another indicator which might usefully be employed is to examine where these graduates are employed. There are some interesting differences in the uses of graduates in Sweden compared with the UK. For example, of the nine Swedish companies for whom the information was available, 42.0% were engaged on R&D or Production Engineering activities. In the UK graduates are much more heavily concentrated with, for example, 72% of graduates being employed in R&D and Production Engineering (Haywood & Bessant, 1987b).

It is clear from the distribution of graduates in the Swedish sample companies, that the more highly qualified people are likely to have a broader view of the activities within the company because of their wider range of activities, which should allow closer analysis and control of the current and future developments necessary for continued competitiveness.

(c) Structures and Functions.

The move to FMS and other integrated automation technologies also poses questions about the traditional pattern of functional specialisation and hierarchies. For example, the need for the design and production departments to work together to develop products which are suitable for manufacture on such systems. Such a "design for manufacture" philosophy is of particular significance and Swedish companies in the sample follow the lines of the need for "Business Systems Engineers" and "Manufacturing Systems Engineers", or "Businessmen" with a more detailed knowledge of production, and "Production people" with a more detailed knowledge of business (Parnaby, 1986).

The essence of such changes are to encourage coordinated skills. This requires the adoption of a single systems view of the enterprise and the scrapping of parochial boundaries between individuals and departments, shortening hierarchies, and broadening skills.

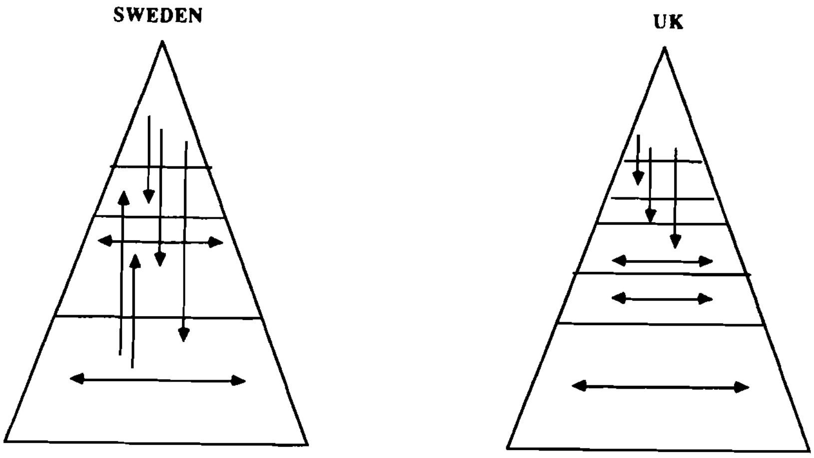
In Swedish companies there were on average, only three levels of management down to the level of the shopfloor worker. This has many implications for border crossing between different functional specialisations within management, and suggests that Swedish managers may be better placed to have an all embracing knowledge of the products and processes employed within the company; a tendency made easier by the earlier observation that graduates tend to be very broadly based throughout all functions of the sample companies.

This contrasts sharply with the U.K where it is common to find six or seven layers, with some instances of up to fifteen levels. However, it is not merely the fact that there are flatter hierarchical structures to aid efficiency and communications, but that movement between levels is more apparent in Sweden.

The trend towards flatter and less structurally functional occupations is being accelerated as a result of the introduction of new technology and the organisational changes that this brings with both vertical and horizontal changes occuring in Sweden; while in the U.K the tendency is merely towards horizontal change.

Strategic changes, such as the above, are also exerting differing pressures in the two countries. For example, while new technology and organisational structures are allowing greater control and information flows in Swedish companies, the devolution of responsibility and the use of higher levels of skills on the shop floor in Sweden has also increased the pressures for organisational change, unlike in the U.K where the upwards pressure is not so apparent. One way of illustrating these differences is offered below (Haywood, 1988).

FIGURE 2. HIERARCHICAL AND FUNCTIONAL CHANGES



Such technological changes aid the most senior managers to obtain a complete picture of the whole process from design and receipt of orders through manufacture and delivery. This increases pressure on middle managers who have traditionally been responsible for functional operationsand, if sufficient confidence about their own ability's exists among senior managers, involves devolving authority as well as responsibility back to the shopfloor worker.

That this kind of managerial self-confidence exists in Sweden was evident from a number of examples given by both managers and shopfloor workers. In one instance established customers with urgent component requirements were allowed to by-pass both managers and supervisors and go straight to the appropriate shopfloor worker with design modifications that needed to be embodied, or to discuss technical or material problems, or even to introduce new and urgent orders (Haywood & Bessant, 1987a).

In another case operators working on an FMS who faced machining difficulties - perhaps because of materials problems - completely by-passed all internal and external company hierarchical structures and directly telephoned the responsible shopfloor worker in the supplying foundry (an independant company) to arrange for replacement forgings. This resulted in replacement components being available within hours rather than the days that this would have taken by going through the formal procedures in an hierarchy.

Given the growing importance of reducing stocks and work-in-progress, allied to just-in-time deliveries, this degree of confidence in both their own managerial abilities and those of their workers is, and will increasingly become, a powerful competitive weapon.

Another result of these changes is that managers , who appear to have traditionally crossed functional boundaries in Sweden, are increasingly becoming multi-functional. Even in the largest of the companies visited - with 7000 employees - it was observed that the individual functional departments, eg, Research and Development, Sales, Manufacturing, etc, were now located within two minutes walking distance of each other for easy contact. In another large firm with nearly 1100 employees, individuals on both the staff and works side were encouraged to go directly to the appropriate person who could resolve problems and make decisions. Yet another company with 4000 employees stressed that a complete reorganisation was under way on the basis of functional coordination.

One other interesting characteristic of the adoption of new technologies in these companies was the relatively low importance given to individual managers or so-called "project champion's" in developing production processes. There was considerably more emphasis placed on developments by multi-disciplinary teams formed specifically for the purpose. The following quotes were fairly typical:

> "Team work is vital"
>
> "Joint development teams analyse and put forward process developments"
>
> "Project champions are not important. It is mostly a collective decision"
>
> "Some small impact from project champions but largely a concensus decision"
>
> "Some specialisms but we insist on a collaborative approach from an early stage. Changes have to fit in to an overall strategy"

The very detailed and constructive suggestions advanced by interviewees with regard to the quality of labour they needed and how best this could be obtained, reflected the strength of their feelings that this was a major component in development strategies for the coming years.

> "I cannot stress enough the need for extra resources to be put into training for new systems, eg, CNC, DNC and FMS, as well as for the development at the local level of a technical high school to upgrade the quality of labour"
>
> "We have strong collaboration with local schools. For example, by the time they are eighteen years old youngsters are spending three days a week working in the company compared to two days at school. From a very young age we encourage the involvement of school children with our company"
>
> "There is already a multi-function training programme in place here. What we should be developing now is an even stronger link with academic institutions in which we can jointly develop appropriate courses"

Without exception Swedish companies perceived that development in processes and products would involve a strongly integrative technology and labour role. This tends to follow what we have elsewhere called Computer and Human Integrated Manufacture (CHIM), rather than simply Computer Integrated Manufacture (CIM) (Haywood, 1988) (Haywood & Bessant 1987c).

(3) EXTERNAL RELATIONSHIPS.

One significantly important reason offered by the Swedish companies for introducing FMS, and a major reason for its success, was the long-term relationship which existed between manufacturers, suppliers, sub-contractors and customers.

Long-term purchasing contracts, economic and technical support, and frequent contact, all established a framework for increased efficiency and reduced costs, and high levels of quality. In one instance a small sub-contractor had been supplying forty different components to the same customer for more than ten years. The following quotes are typical:

> "For some time now we have had strong links into a more limited number of suppliers, often paying ourselves for their costs in tooling or jigs. Cooperation is the keyword. If someone qoutes too low a price for a job we would query it since it could lead to a lower level of quality than we desire"

> "We helped one sub-contractor to relocate closer to us, helping them with building and equipment costs. We also use our own position in the market to purchase materials and equipment for supplier firms"

> "Although we are a fairly small company we have 300 established customers including some of the largest in Sweden, eg SAAB, Volvo, and ASEA. These have mostly been long-term relationships and I would estimate that 95% of Swedish companies have such long-term contacts with their customers and suppliers"

Almost all of the small to medium sized companies that were sub-contractors to larger companies had order books in the region of a rolling average of one year - in contrast to the UK where it is normally in the region of three months (Haywood & Bessant 1987b). Such continuity allows Swedish companies to have a longer-term planning horizon and facilitates the use of new and sophisticated equipment, since the return on capital is secure.

Several instances of larger companies installing expensive equipment at their suppliers sites were also seen. This infrastrucural support is reinforced in many instances by direct assistance in the purchase of materials at preferential rates by the major companies for the smaller ones.

These factors bring substantial benefits to sub-contractors by expanding time horizons; but also aid the major manufacturers by keeping prices down, quality up, and improve delivery times. This is in contrast to the UK where, in general, it is considered "Impertinent to tell our suppliers how to produce the parts that they do for us" (Haywood & Bessant, 1987b). In Sweden, it is considered to be both appropriate and sensible.

CONCLUSIONS.

A number of important factors have emerged from this analysis of the adoption of FMS in Sweden and the UK, both in terms of strategies and policy implications. These are, of course, generalisations, but whereas in the UK only a few of the companies visited have adopted technically, organisationally and structurally integrated methods, in Sweden only a few companies have not adopted them.

(1) In terms of company efficiency Sweden has twice the level of turnover per head employed (£69k to £34k), only 60% the levels of Stocks Held and Work in Progress, and this represents only 22% of total costs compared to 37% in the UK.

(2) Investment in higher technology and in high cost technology, is perceived as "normal" in Sweden and return on investment achieved over a three to four year period. In the UK it was mainly considered a "strategic" factor with costs not usually recovered in the normal 18 month to 2 year investment period.

(3) In the UK it is usually the case that traditional criteria of labour cost savings are dominant, whereas in Sweden it is viewed as "freeing up" labour to move to other areas within the company. Job loss - though obviously not entirely consequent on the adoption of new technology - in similarly sized companies in the two countries, was six times greater in the UK (8% to 1.2%).

(4) Educationally,in excess of 75% of Swedish school leavers went on to further education compared with only 30% in the UK. Strong school level links exist in Sweden including placement in companies and staff exchanges between schools and company's. Additionally, these links are growing with the foundation of "corporate" high schools by company's such as Volvo and SKF.

(5) As a consequence of the above, graduate employment in the companies visited had risen to almost 10% of the total numbers employed in Sweden, this compares with under 3% in the UK. These graduates were also found to be more widely distributed through all company functions, unlike in the UK were they were normally concentrated in a narrow range of occupations.

(6) There tended to be only a limited number of levels of hierarchy in the Swedish sample (usually 3/4), but double this in the UK. The introduction of new technology gave the opportunity to senior managers to obtain a much clearer picture across all functions in the company. This downwards pressure on hierarchical structures was similar in both countries. However, in Sweden strong upwards pressure was also evident as a result of the devolution of responsibility and authority to the shopfloor worker. This latter trend was not evident in the UK.

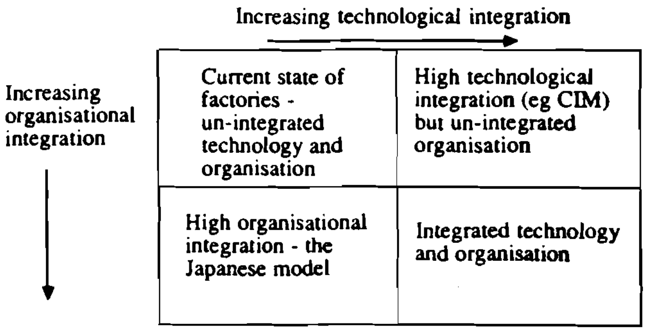
(7) The inter-linkages between manufacturer, customer and sub-contractor that was seen everywhere in Sweden was not so clearly identifiable in the UK. The benefits that are apparent in Sweden as a result of these links, eg, improved delivery times, higher quality considerations, maintained or reduced costs, and the use of more modern technologies as a consequence of long and repeated contracting relationships, were not as clearly established in the UK.

(8) Finally, the integrated whole that brings together technology and skilled labour of all levels (both shopfloor and managerial) in Sweden, was absent, in general, in the UK. This approach, which we have called Computer and Human Integrated Manufacturing (CHIM), appears to us to be superior to the more normally considered Computer Integrated Manufacturing (CIM).

The result of these integrated policies; the high utilisation of equipment; the efficiencies achieved; and the realisation that human factors have an extremely important bearing on job satisfaction and improved competitiveness, leads us to the conclusion that the Swedish experience offers us an alternative and more efficient way in which to develop production processes.

We might then expect that integration developments might be reflected in changes in the following matrix that are predominately in a south-easterly direction, combining both technological and organisational change.

FIGURE 3. OPTIONS IN THE MOVE TO INTEGRATION



Increasing organisational integration ↓	Increasing technological integration →	
	Current state of factories - un-integrated technology and organisation	High technological integration (eg CIM) but un-integrated organisation
	High organisational integration - the Japanese model	Integrated technology and organisation

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6. KEYNOTE POLICY DISCUSSION

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KEYNOTE POLICY PANEL

CIM CONFERENCE

Wednesday, 4 July 1990

Keynote Policy Speakers:
Chairman: Prof. HARVEY BROOKS *(Harvard University, USA)*

So as to provide a broad overall framework for the policy discussion, let me just read a short paragraph from Prof. Uno's presentation yesterday which I think provides an overall framework which I hope we'll keep in the back of our minds in the discussion of policy implications. He says: "The world is beleagered by environmental disruption and resource exhaustion. Continued economic expansion seems to be incompatible with the limits imposed by the environment. Heretofore technological change centering around "CCC"–Computers, Communications and Control–and reorganization of our economies incorporating such change, seems to be the only feasible solution to safeguard sustainability of our global community." With that sort of framework I now call on Prof. Ayres, the first speaker.

Prof. ROBERT U. AYRES *(IIASA, Austria)*

Our intention was that this should be a very informal meeting, and it will be. I have not prepared a written speech. I'll do my best to wing it here--excuse the slang. My starting point for this whole project in a way, was the thought that if we are indeed in the first stages of an industrial revolution of major magnitude--which I take it to be the case--then what will historians and social critics in the year 2050, looking back, say are the most important problems? What are the changes that really matter, that result from this industrial revolution? To put that in context, remember that the first industrial revolution wasn't recognized for what it was for 40 or 50 years. It was named by Toynbee (1880's) as an important "sea change" but occurred in the 1830's or 1840's. But that's a long time after the beginning. By that time many of the social ills that still plague the world were well established. For example, the factory system, deskilling and the exploitation of child labor; the extremely poor working conditions and long working hours the rise of the "capitalist class" as a social class with huge social gaps between the owners and the workers, this led on, as you know, to a kind of allergic reaction in the form of utopian socialist theories. Marxism, communism, which in turn led on to single-party governments with central planning that are still plaguing the world. It is now 200 years since it all began.

I wonder what the corresponding social problems might result from the set of changes that are beginning now. I don't have the answers to that. We began this project with the idea of at least delineating the parameters and formulating some of the questions. I hope we have done that.

Now let me just mention some of the categories of policy issues, which perhaps could be addressed by the other panelists today. In comparing the situation today with the situation that followed the first industrial revolution, I have to say that the first time around none of the social consequences were anticipated, nothing at all. What occurred thereafter occurred as a result of evolution. Perhaps the process was quite closely analogous to biological evolution, except that we didn't have anything analogous to mutation. But everything that happened from James Watt on was a short-term reaction to something else. And I think it is fair to characterize that whole process as "myopic". Society responded to short-term challenges, short-term threats or apparent threats, and short-term opportunities.

But the world is more complex now. The threats of--for example--climate change and world environmental degradation are growing severe. For that matter the threat of nuclear war hasn't disappeared. It seems much abated today as compared to a few years ago, but it still has not disappeared. As long as there are many thousands of nuclear weapons, the threat remains. We can't afford to just "let things happen". We must begin to look forward. People, like the people in this room, are the ones who have the capability of doing that. We must find some way of making our forecasts and policy recommendations, heard, by those who actually make political and economic decisions. That topic should perhaps be part of our discussion.

In any case, the policy categories that quickly come to mind include *industrial policy*. Some countries have very successful industrial policies which are very closely related to the adoption of CIM, and closely related technologies; others (my own included) pretend that there is no such thing as industrial policy, or that industrial policy is a bad thing because the government never makes the right decision. What should countries think about in terms of industrial policy to make this transition to CIM more acceptable, less painful, less shocking, less dramatic.

Another area is trade policy. Every country has trade policies. Sometimes again, they are not recognized as such. Labor policy is an important category. Of course, everyone is worried by the possibility of job losses and unemployment. In Europe labor policy is clearly very central. It's part of social policy. Our Scandinavian friends are the first to tell us how important that is. What does CIM imply for labor policy? Social policy is very closely related, but I am particularly struck by one particular aspect of it that has been emphasized by a number of social thinkers and social critics. Namely, it is suggested that automation portends the decline of the middle class. The middle class has been an extraordinarily important component or element in the structure of society as it exists today. I think democracy depends very much on the existence of a strong middle class. If somehow the advent of CIM and related automation led to a two-tiered society with a bunch of "elite" managers and experts on the one hand and a large group of untrained, unskilled people doing janitorial tasks and road maintenance, on the other hand, it would be a very serious problem. I think at least some decline in the middle class can be seen. The power of organized labor to force wages above competitive levels is certainly declining now. I don't know if that, by itself, means the end of the middle class, however. There seems to be a growing need for skilled technicians, for instance.

Another area is education policy. There has been much discussion of training and the importance of training skill-based technologies. Training depends ultimately on education. Education is what makes people trainable. Not everyone can go and learn how to use a computer, or a workstation, in a week. A highly educated person can do that, but not someone who is barely literate. So education is the foundation for training and education is clearly an issue of great importance from the policy standpoint.

And then, finally there is the issue of international development. We have a world of rich countries--OECD countries plus some countries (NIC's) that aspire to reach that level in the relatively near term. But we have also a lot of countries caught in an extreme poverty cycle. Many of them remain in their present state largely as a result of misguided policies adopted 40 or 50 years ago. Policies that, for example, stressed import substitution and investments in heavy industry but neglected agriculture and eduation now look to be very inappropriate. I mentioned briefly two days ago the possible threat that CIM poses for the developing world. Because the LDC's must get away from a situation where all they can export is raw materials. Yet most LDC's cannot produce any manufactured product that is competitive, for quality reasons, in the OECD Market, this is a real challenge. What does policy have to say about that? These are some of the questions that I would like to be addressed by the Panel.

Prof. R. BOYER *(CEPREMAP, France)*

I want to follow up on what the previous speaker said and to give to you my reaction to the vision of Bob Ayres and then to work a little bit on the agenda. I prepared notes on the same items as Bob, so I will build on his first intervention. First I would like to offer what I would call the "Ayres paradox". You know that Bob Solow wrote in the New York Times Book Review "We see the computer everywhere except in the U.S. productivity statistics". Let me offer you the following paradox. Here we see CIM everywhere except in the productivity measure of effective productivity. Why? I think this raises an interesting question. I would propose to you four ways of interpreting this.

First, is of course that CIM is a global process and you have to synchronize what is happening regarding this very sophisticated technology. With all that is going on at the economic level, and I quickly appreciate Prof. Bessant pointing out that the transformation of management is under considerable pressure here and maybe this transformation is not so easy, because you have on one side engineers speaking about quality perfection of the technical side, and on the other hand the guy optimizing the short run.

Second question, and here I want to argue with Bob Ayres. Is organization the leading factor or technology?

Let me for simplicity sake pose two visions of it. One we could call epistimology and the other would be technique. In epistimology you have the basic physic law and the mathematics. Then you derive one best way, you apply this and the manpower requirement is exactly what is derived from this. For example, you might recognize scientific organization Taylor, Ford, and so on.

But you have another way which involves technique. You have a craftmanship which does not involve the exact physical laws, but by expertise, by training, it can arrive at new principles. Maybe the Japanese, Swedish, or some Italian firm, such as Ford of Italy do belong to this model. You have highly trained people who have learned to cooperate, and then they could invent new products and new processes and in such a way they could incorporate new technology given their own expertise.

I think now that I would like to blur the destinction between the two. Maybe one of the reasons for the Ayres paradox would be that you don't have the synchronization between the organization and the technology.

Thirdly, I was very struck by the importance given by every participant to the learning process . This new equipment is so complex, so sophisticated, that you have to learn how to use it and of course during the running period you don't get all the results which are to be supposed. Therefore you have to organize networks to integrate, to break down functional specialisation and this takes time. You must explain why potentially you get huge productivity increases, whereas the organization fails to move as quickly as required for these productivity increases.

But let me mention a wonderful parallel between now and the second industrial revolution. I hope everybody in this room knows the wonderful paper by Paul David of Stanford University comparing the computer revolution with the electrical engine revolution. It took two or three decades to generate new productivity gains associated with this very revolution. Why? Because you have to train engineers, technicians, to achieve norms, to get the whole reorganization of the firm, and feel what is going on to solve the paradox now is the huge social process of adapting infrastructures to the new opportunities.

The reason for such a productivity paradox could be the following. The process is revolutionary, but it also takes time to achieve. It is a silent and slow revolution in such a way that you need time and maybe it is occuring at the time of the so called Kondratiev wave. I regret Professor Chris Freeman is not here because the time of the Kondratiev wave is exactly the time of infrastructural imbalance and so on.

What are the consequences for economic policy. Let me discuss six items very briefly. One basic question is the following. Are there one or several models in adapting the new CIM system? One answer has received a lot of attention in this room. And personally, I have been writing on this for the OECD in a Helsinki paper. That is that you have common principles on Just in Time, quality optimization, networking, integration, expenditure, production marketing, etc. So you have basic principles. But according to the individual societies in which we live you have strong unions or weak unions. You have a strong manager or a weak manager. You have a tradition of authoritarian or democratic relations. Therefore, you will find very contrasting ways of organizing the same functional principle.

I would adapt a kind of – I am sorry to be so academic – a Gerschenkronian hypothesis. You have one model but trying to implement it you are inventing quite a new model which is a very important idea because it provides some degree of freedom to each nation. You are not obliged to copy one best way, you have a lot of variety and if this is true then economic policy matters, because you can try to implement CIM according to your own specificity.

The second factor. CIM is a very long-run process. A revolution was supposed to be like you see in the Soviet revolution--very quick. But the revolution Bob Ayres is mentioning is a very slow process of industrial revolution. Therefore you have to be very patient and careful, because it is a long run strategic policy. It is not short run, swift and rapid. You have to adapt to a long run. However, as I was told in my planning institute, in order to prepare for the long run, you have to be very fast and very early at the start. If not you are missing some of the basic points. It is not a long run process in which you can wait. On the contrary, you have to start on a good track. I think the basic point would be regarding skill formation, product renewal, rational imbalances, and so on. So we have to start right now.

The third problem is, "what are the big challenges". Let me raise another paradox. I am struck that by training the engineers are looking at the potential application of new technologies. But on the other side, the quotation by our chairman about Uno's paper is very important, you have basic and felt needs in modern stable society. Let me mention some of them. (A) The population is getting older and older and this raises major social problems which will not be solved easily by the computer, and so on. (B) You have education. Education is mainly a question of training people. Of course, the computer can help but it is not a solution. (C) You have pollution. (D) You have to learn how to manage huge public organizations, welfare systems, banking, etc. Therefore I think what would be interesting is to try to extend what has been done for the manufacturing sector to the service sector. What could be done to solve one of the major problems, the quality of life, pollution, and so on? Not so much in the product manufacturing sector in which you see we can solve the problems. So it would be a kind of mixing, a social requisite with technology. Maybe you could find a brand new implementation of new technologies.

Thirdly, everything has to change. If it is a revolution then you cannot stick to the old Fordist generation style of making policy. Management has to change. Under the Fordist model you have to optimize the downgraded scales. Now the name of the game is the opposite. To permanently upgrade skill, and so on. In some cases you have a complete reversal.

Fourthly, another problem is that competition used to be about cosmetic differentiation or price competition. In the new model you are competing for quality, for service, for marketing, and so on, which changes completely. Zuscovitch mentioned yesterday how important this is for economic policy.

Fifthly, we should also consider industrial relations. In the new model you need strong cooperation within the firm. And what about countries such as the US or France where you have very adversarial capital/labor relations. What do we do about this new model? This raises huge topics to be dealt with. How to introduce this new model in countries where you have strong opposition. This is not an easy process and, for example, there are many difficulties in France because if you have distrust between managers and employees it is difficult to cooperate. Similarly between firms or industries. Everything would be discussed in confrontational terms. This is a major problem, for example, for US industrial relations or France, or the UK, etc. Maybe this is much more important than pure technological policy because it is in everyday life that we are working on productivity and quality.

My sixth topic, and since we are in Vienna I will be a little bit Schumpeterian. Financial capital is of paramount importance for CIM. If you cannot attract long-term or short-term capital, or banking credit in order to implement new technology you could not challenge your competitors. I have been making comparative studies with a network of fellow researchers and was very struck that the speed of technological adaptation is strictly correlated to the density and the quality of the links between the financial sector and the industrial sector. If you have long run relations you can have a technological and very innovative policy. If you have only volatile stock markets and short run control then it is very difficult to make breakthroughs in technological advances. The opposite side of the coin features Japan, West Germany, Sweden with a lot of integration, compared with the English speaking nations such as the UK and US.

My seventh point, let me again mention education. I was very struck by Tom Astebro's claim that after all the speed of diffusion of CAD one of the most prominent explanatory factors was the level of education. Therefore you see a strange effect, it is not merely, per se, the technological ability or the tax system, or so on. It is the general level of education which is a pre-requisite for this kind of implemention.

Eighth, is industrial and technological policy. If all the items mentioned above are fulfilled, you need a very minor industrial interventionist policy. In the Fordist regime you have just the opposite industrial policy. In the new regime, if everything works smoothly in the credit market, industrial relation, education, you need only minimal industrial policy just enough to fulfill the norms of the basic infrastructure.

Let me end with one joke and one warning, and one quotation. The joke is the following. In France we had a General who prepared to win the last war. He built the wonderful Maginot line. Of course, our German colleagues invented new forms of war and we lost the war. Maybe economists or technologists are on the same track. If you prepare to win the Fordist battle, you may lose the new CIM battle.

But let me now offer the warning. The warning is that you can make two symmetric errors. The first is to be very myopic just to see what is going on at the moment or has already occured. But you have an opposite danger -- to be too visionary. CIM will be a common practice tomorrow, and I think the usual trick should be to adapt a combination of purely myopic vision and the visionary, taking into account all the forecasts we made after the 1950's about automated society. It would be very interesting to go back and to learn from some of our very distinguished friends who in the 1950s forecast that manual work would totally disappear around the 1960s and the 1970s. So we should be very careful.

Finally the quotation. "The difficulty of new ideas is not the novelty of ideas but that we are prisoners of some old ideas." And what is good in this conference is that I was very struck by the novelty of the ideas but also eventually to master them, and to convert them into an economic policy relevant agenda.

Dr. K.H. EBEL *(ILO, Switzerland)*

I should like to address two issues. One employment and the other one industrial relations. Well, I was struck by the contradiction actually that we saw in this meeting between types of models and forecasts, and the actual reality when it comes to the employment of advanced technology. We certainly have a shift from a direct to indirect labor. A gradual shift. Then also a gradual elimination of unskilled manual jobs. And we will end up, again gradually, with a different occupational structure. That is certainly true and that is accepted. But I still cannot see the tremendous impact of advanced technology and of CIM on aggregate employment, lets say in the metal trades, and on the labor force in general.

There is nothing in the trends in the statistics that, at least in the evidence that I have seen, which says that there will be major impacts that have been forecast. So, why is that. Perhaps there is an explanation. Because there have been studies which show that only about five to seven percent of the labor force in the highly industrialized countries is actually working with this high technology, and advanced technology types of programmable means of production. So, of course, the proportion of people working in high technology and advanced technology will go up, that is certain. But only relatively slowly. And I think there is some reason for saying, and it has been said, that one of the driving forces actually for this type of technology is the shortage of skilled labor. If we had more skilled labor we might have less advance in CIM. Are we only faced with time lags, are we only faced with a delayed revolution or will we have a revolution, is it a very slow revolution, never mind what it is, but I think it is going very slowly. And I think it is wrong to have a general scare, and a general sort of fright actually produced in society, saying, well, this technology will eliminate all employment.

We might have considerable effects in the field of employment, aggregate employment, but for quite different reasons. For economic reasons. Perhaps a reconversion of industry, of the armament industry for instance, might have much greater effects than CIM or the other advanced technologies. So that is the remark I should like to make. There is no need to panic in this field.

The second point, of course, is the question of industrial relations. I think we have to face the actual fears of the work force, the labor force. What do they fear? Pay losses because of reduced overtime? Of more shift work? Of course, of certain redundancies, lesser career promotion prospects, for instance. Machine pacing of work and intensification of work. The fear, and particularly in the engineering field, of the expropriation of know-how through data bases in CAD for instance or in expert systems. There is evidence that there is much more stress in modern production systems which are more psychological than physical.

Then there is the danger of individual performance monitoring through computers, which has caused quite a lot of trouble already in some countries where it is not forbidden. There is a danger of deskilling and also the possible loss of acquired rights and benefits. Now I think these fears are realistic and up to a point they are justified if they are not addressed and they must be addressed. To overcome this and to use the opportunities of CIM and of advanced systems one must come to a dialogue, to a consensus and cooperation between management and the work force, between the employers and the employees through genuine consultation, possibly through technology agreements to address these issues. Only then will it be possible to reap the benefits of this technological revolution. And there are such benefits. These include safer and better jobs, better working conditions that can be achieved because this technology is extremely flexible.

You can do it one way or the other. You can have an exploitative situation or a much more cooperative situation.

There are better learning and training opportunities, if the technologies are addressed properly. You can create career patterns which are feasible with this new technology. But you must do it consciously, it won't happen by itself. Of course, you should give people this responsibility, and better responsibility, but here we should watch out. We cannot give more responsibility to people without preparing them properly through training. And this issue has only recently been addressed. We will have a need for more decentralized decision making. It can be done. But this technology can also be used to centralize decision making, much more so. How are we going to address these issues?

Then, of course, I think the question of remuneration and benefits will have to be addressed. People will have to feel that they also benefit from this technology. And one, and perhaps the most important thing, that you have to ensure a certain degree of job security to people who are working with this technology. That is perhaps the most convincing argument you can have in a competitive and in an advanced enterprise.

Now, I am firmly convinced that the arbitrary exercise of management prerogatives can kill CIM in advanced technology. There are examples that it just doesn't work without dialogue. So there is this need for dialogue. Adversarial, industrial relations are definitely counterproductive and we have seen the paralyzing effect of industrial disputes on advanced technology. Again a committed and qualified work force that you need, doesn't just suddenly emerge. It demands a great of hard work on both sides.

Now a warning. We have control system possibilities, computer control and monitoring and all these things, and it has been tried. I think, and here again there are examples, that one should not underestimate the ingenuity of the work force to evade such control systems if they really try. And that we have seen through industrial history that this can be done.

Of course, there is a decline of union power that we see at the moment, but this may not be a permanent feature that has historical roots because of the union organization, but we also see counter trends so I don't know whether this decline of union power that we have been observing in the past decade, well two decades practically, is really a permanent feature. I doubt it somehow.

I'd like to stop here to give some time to my colleagues. There may be time to speak again later. Perhaps one last thing. I think it is quite important, and that is for all the professors and engineers here, to design the CIM systems, the modern advanced systems with the human factor in view. And that is very often forgotten.

Acad. IGOR M. MAKAROV *(Presidium USSR Academy of Sciences)*

The main objective of the research provided by the CIM Project and related national institutions is the systematization of knowledge about ways and prospects of development of flexible computer integrated manufacturing. This knowledge has great importance in view of the fact that computer based production automation now presents, and clearly will represent in the future, one of the mainstreams of scientific and technological problems.

In general, the essence of the problem we deal with is the knowledge acquisition process aimed at answering these questions. How one can distinguish between successful and unsuccessful strategic thinking applied to CIM development?

The complexity of these problems stems from the intelligent origin of such cognitive processes which creates many obstacles to conventional formal technique, if we try to use it for research purposes. Therefore we used for the study complicated hybrid expert systems which include the knowledge base and the decision support system. All these techniques are productive tools in acquiring such knowledge.

Since my colleagues have talked about revolution, I can say a few words about it too. At this point let me agree with the opinions expressed by Prof. Ayres when he called the emergence of micro processors and personal computers a revolutionary step in the rise of new technologies. I would add science and research as well.

In todays world other processes are also taking place. For example, in the Soviet Union the emergence of Gorbachov has also created a political revolution or situation, not only applicable to the USSR, but also other countries. This will help such progress.

In the field of computer based manufacturing the area of fundamental theoretical knowledge describing how strategic decisions affect their development is, so far, quite limited.

In our opinion that is why deductive methods do not give much support in the early stages. The opposite approach to inductive reasoning provides the ability to analyse practical experiences, and clarify the major priorities which contribute to the success or failure of practical FMS/CIM cases.

Such an approach is not new. We know about the method of plausible inference by J.S. Mill, and this was applied in many works. One example is the work based on decoding genes in the USSR under the guidance of Acad. Spirin and Mersabekov, which has had good results. The inductive approach has successfully been implemented to biotechnology. For example, for cellular genetics and engineering decoding, and so on.

Very similar to that approach, but with modifications for our purpose, we have used expert systems to analyse the priority structure influencing the choice of CIM development strategies. CIM strategies are built on the basis of knowledge about product demand changes, however, it is usually difficult to proceed directly from demand changes to decision priorities. In our research it has been shown that under such conditions the way to analyse strata profiles has proven to be much more productive. The collected strata profile data provides firm basic knowledge for the synthesis of generalizations in the sequence of type demand priorities in strategic decision strategies.

The application of strata scenario analysis to the FMS base, with cases from different countries, helps to infer many conclusions with respect to CIM development trends in general. As well as this, to the evolution of certain key features like integration, degree of automation, flexibility, economic rationality, etc. All these particular features are provided in the paper we presented at the conference (Makarov, I.M. & Rakhmankulov, V.).

Let me say a few words about our conclusions. First, a general conclusion confirms that Computer Integrated Manufacturing is developing along active growth lines and taking the shape of a new quality due to accumulated knowledge and the learning curve. Efforts to study CIM have to be made deeper, and certainly there should be a difference in the country profiles or labor education as it was said here.

Integration, the second conclusion. The artificial push and pull of integration leads to rapid growth, of course, especially in software. It is necessary to step up in terms of integration, only after problems like standardization, unification, turnkey proposals have been solved.

Third, the degree of automation. The natural development of technology should not be overlooked. Striving for total automation is proving to be hard to justify, rather there is a need to combine man and machine.

Fourth, on flexibility. Short trend purposes should not force CIM designs to be shifted from favourable batch production towards mass production. It might reduce the product cost but equally it could increase overhead costs.

Finally, at the early stages of adoption of CIM, major priorities were allocated to control systems. Quality and manufacturing services were in the background. Now, major priorities are to close cooperation between control systems and quality service systems, such as, total quality control, Just in Time, material resource planning, etc.

In conclusion, I would like to underline the universal nature of the considered approach which could be used not only for computer based manufacturing, but also in those directions where there is a need to study or build development strategies.

Prof. KIMIO UNO *(Keio University, Japan)*

Being at the end of the panel, I am a little disadvantaged by the fact that the major issues have already been touched upon. Nevertheless, I want to raise three points. First, is why I personally use the term CCC--Computer, Communication and Control--rather than CIM. I am not criticizing CIM, but from the point of view of the broad economic repercussions I believe CCC would be a better term, because of the fact that if you say computer it is not a computing machine, as we know, but perhaps the most important thing which is the development of databases of various kinds which embodies the stock of knowledge.

We actually have a common framework of knowledge which can be shared globally. That I think is an important phenomena which is now taking place. Up to the present time, and before the introduction of the database, the stock of knowledge existed in abridged form, perhaps since Gutenberg invented the printing press five hundred years ago. But the technology has remained virtually the same for that period of time and at last we are changing that. We are exchanging and publishing our ideas via databases which are accessible on-line.

My second point, the second C stands for Communciation and I think that is very important because it is the prerequisite of a horizontal network society rather than an hierarchical or vertical one. We are finally achieving a network organization and that changes the nature of management which should change the nature of work, and subsequently implies teaching in different ways in our Universities, Polytechnics, and other institutions.

With regards to my final C, Control. Of course, CIM falls under this heading including CAD, CAM, robots, numerical control machines, etc., but of course our CIM projections have to include logistics, that has already been carried out. Control is also now appearing in our offices and in various social life aspects, such as traffic control, hospitals, leisure activities, and finally, even in our homes. So, the introduction of CCC is not only changing our factories, but our offices, our homes and our society as a whole. In the end, of course, that will be affecting our quality of life.

The second point I want to raise is the occupational aspect which has been repeatedly touched on in this conference. Suppose you have an industry occupation matrix which I included in my paper yesterday. I am now talking about row and column figures of this matrix. The impact of introducing CCC technology is felt in assembly industries, such as, electrical machinery, general machinery, motor vehicles, other transport equipment and precision instrument. That is almost our CIM sectors. The important thing about CCC is that the impact is felt in wholesale and retail areas, public administration, business and private services. As we all know, the labor input coefficient has been on the decline in manufacturing sectors. But the fact is that our society has not been able to reduce labor input in services more broadly defined, so that sector remained more or less inefficient as compared to the manufacturing sectors. Finally, the introduction of CCC is changing this industrial contour, which is a very important development.

The other aspect of employment is the occupational pattern and that can be characterised by male and female differences because in certain occupational categories you employ more female workers than male, and vice versa. According to my research of professional and technical skills, occupations are influenced but the introduction of CCC tends to reduce the need for professional and technical workers. When it comes to managers and officials, the effect has not been felt. Maybe because decision making is becoming important or remains important. This may change in the future, but as far as our past experience is concerned, this category has not been effected very much. When it comes to clerical jobs, the effect is quite distinctly felt for both males and females. This is also true of sales workers, though female workers have been more affected by the introduction of CCC.

In the case of transportation, the effect has not been great. In the case of production process workers the effect is distinct. As for workers in the service sectors more effect is again felt by female workers. So, the arrival of CCC perhaps is affecting less experienced female jobs rather than overall occupations. That is my second point.

Third, is the investment aspect. The introduction of new technology is not just a case of inventing something in a laboratory or workshop. It has to be developed and diffused and put into place in our society. At the initial stage, risk taking/risk sharing function is very important perhaps in undertaking R & D and investment itself. The availability of credit is very important here, availability to credit in a Schumpetarian sense because this is the mechanism of the capitalist economy whereby the limited savings fund can be channeled into a more productive sector. Savings can be turned into credit of some magnitude through credit creation by the banking system. And this credit creation by the financial institutions should be emphasized in discussing the diffusion process. An investment, of course, includes investment in intangibles, like software, know-how, etc, and we should explore this point more fully. In particular, on the point that knowledge production and maybe the accumulation of knowledge is quite different from what we have, or what we know, about the production and accumulation of hardware. Perhaps I am now coming back to my first point whereby I highlighted the pursuit of a stock of knowledge is finally to be examined.

FURTHER DISCUSSION

AYRES

I have a few comments I'd like to make responding to points made by others. First of all, on the adversarial tradition. It is true that countries differ a lot in terms of how deep the adversarial tradition is. I think the US is probably the most adversarial of all, at least in labor/management and inter-firm relations. Then the interesting questions are why? Part of the reason must be historical. Everybody knows how many lawyers we have in the U.S.—or at least that we have far too many. Understandably, they try to keep themselves busy. Somehow the effect is to shape the whole social system, for instance, you have to have a formal contract for everything, and that means you need a lawyer; and then you fight about things, and that requires a lawyer. What policy levers what hooks have we to change that? I think it is clear that it needs to be changed. I don't know how you change it, but that is a subject that we need to think about.

Another point has to do with the long run versus short run attitudes, as Professor Boyer mentioned. Again some of the reasons may be historical, some of them cultural. For example, Japan is reputed to have a much longer term tradition, or at least the present outlook of business leaders tends to be much longer term than in the U.S. People look further ahead in Japan. If we understood better why that is, then we might have some idea what could be done about it. And again I wonder, without knowing the answer, what are the policy levers to change that?

One thing that might not be immediately obvious, but probably is one of the factors, is the law regarding ownership of large firms. The reason Wall Street has so much influence over corporate management today is that large banks are not allowed to control large corporations as they are in Japan and Germany. That law was put into effect in the 1930s as a reaction to the stock market crash, when it was thought that somehow the banks were responsible. Now, in retrospect, it appears that the banks were not the villains after all, but the restrictions remain.

One more comment about the Solow paradox. I am not sure that it is quite true. I have seen recent figures suggesting that manufacturing productivity in the US has started to accelerate since 1980. Total productivity growth is slow. But that is partly because so much of the economy is now in services, where productivity growth is admittedly slow. As you probably realize, the manufacturing sectors of Germany and Japan are about twice as big, relative to GNP, as it is in the US. This tends to drag down aggregate productivity growth for the U.S. relative to countries with smaller service sectors. Prof. Kodama of Japan has noted that direct investments in fixed capital for more then half of the large companies of the top 50 companies in Japan has started to decline. Which would seem to be evidence that capital productivity is beginning to rise, perhaps as a consequence of CIM.

BROOKS

I might comment on one point you raised. The question of long time horizons. I think one factor in the long time horizon in Japan that has not been given sufficient emphasis. But the fact of the matter is, if you have a rapidly expanding economy you tend to have a much longer range attitude because you know that expansion will essentially overtake you, so to speak. In other words, especially if you combine it with the notion of the learning curve, you can make investments for the long term because eventually those investments will pay off if the economy expands, whereas if the economic markets are more or less saturated, then those long term investments will become much riskier. In fact, these periods of rapid expansion tend to be periods when long term investments have a greater pay-off.

EBEL

I think there are certain breakthroughs in particular in the US in the industrial related field. I think there have been training agreements there between the UAW (the machinist unions) and certainly among the large companies. I don't know how far this is really percolating to the smaller and middle company sector. I think there is hope for more cooperative consensus relationships.

Incidentally, there is something quite interesting which I should like to quote which has just come up this summer. There is a proposal for the right to strike over production qualities being considered for inclusion in national contract talks between the United Auto Workers and General Motors Corporation. It goes on to say, "Attributing recent quality problems to management, UAW officials noted that union efforts to battle poor design and slow product development cycles have been snubbed. The right to strike plants would safeguard the quality necesssary to maintain our jobs", said the union. This is a very interesting attitude and change, and actually puts the finger right where it should be put, because I think there is a tremendous responsibility on the part of management to say what is happening in industrial relations and what is happening to productivity and organizations. The biggest stumbling block is, what I suspect, not so much top management but actually middle management interest in the continued existence of power structures. To change that it is not an easy thing. How do you change organizations, that is the big question.

MAKAROV

The problems we have discussed have been developing for several years. There have been many stages in the past, and now it is necessary to have deeper and more serious analysis of what was done or, what will be, and this is proved by colleagues who have discussed changes in, for example, the US and other countries. In the Soviet Union we also have changed the use of, for example, robotics and their connected issues. Now is the stage to think in a new way about such developments.

But I hope that this direction of flexible manufacturing and flexible automation will continue in the long run and that there will be achievements, such as those several years ago in Japan where they studied in some depth future plans. We are not at the end of developments, but in an evolving scenario.

UNO

Short term vs. long term in investment and/or in the social settings. The reason why Japan tends to have longer views is perhaps attributable to two factors. One is my hypothesis about the various constraints imposed upon our economy. One perhaps is the lack of resources and second is the lack of savings funds, at least in the past. This is not true anymore, but up to 1970 we were very forward in real investment but based on a rather poor savings basis. So this has to be worked out and consensus has to be reached on which investment would be taken. These facts especially resulted in different patterns of the division of labor within Japanese economic institutions. There were producing units, financial units, and sales and marketing units, all separated. On top of them we had government organizations which attempted to coordinate among various sectors. Consensus has to be reached amongst them.

The second hypothesis is management responsibilities, which is that in the case of Japan, the management works as a clearing house of information rather than being the decision makers within it. In other words, the management should function as a part of the network and its function is to listen to what is being done at the bottom and to be able to communicate to others in the society rather than making the decision by itself. In other words the decision making is made not top down alone, but bottom up as well. That means consensus has to be reached and consensus is only possible if you had common knowledge.

7. CIM IMPLICATIONS FOR GOVERNMENTS AND INDUSTRIES

Implications for Governments

by

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CLOSING KEYNOTE SPEECHES

PROF. HARVEY BROOKS

"IMPLICATIONS FOR GOVERNMENTS"

What I have done is list eight possible areas of government intervention which are intended to deal with both the promotion of the technology and its possible adverse effects. I would just like to spend the 15 minutes I have been allotted to summarize each of these points briefly.

First of all, I think one of the most important implications of CIM, and in fact the whole collection of what Prof. Uno calls the CCC technologies, is the need for active labor market policy. What I mean by an active labor market policy is essentially two things-- (A) Labor retraining, training to promote labor mobility and versatility, and (B) a system for matching new job opportunities to people. I think it is no coincidence that if you look around the world at the countries that have been most successful in keeping low unemployment rates, they are countries which have invested a great deal in labor market policy either as in Sweden in the public sector, or as in Japan largely in the private sector. I have made a calculation that if the U.S. invested as much in labor market policy as Sweden does, in proportion to its population, we would be spending about US$200 billion a year on simply matching jobs to people and labor retraining. That gives you some idea of the orders of magnitude involved.

I think one of the most important aspects of an active labor market policy has been the capacity of the countries that have it to phase out obsolete industries with minimum degrees of dislocation and that probably is the most important aspect. The emphasis, of course, should be not on job preservation but on employment preservation. I think it is very important that this destinction be made. In Japan this happens mainly through a great deal of internal mobility of labor not only within the companies but within the company associations, including their major suppliers.

The second point is one that was emphasized by Bob Ayres this morning, that is basic education for trainability and I like that way of formulating it. One can't in fact have a good labor retraining policy unless one has a labor force with basic general skills. This is an area in which the US emerged from World War II in a very superior quantitative position relative to the rest of the world. We only realized that our superiority was quantitative, and not qualitative, when the rest of the world caught up with us quantitatively. Then we found that the rest of the world for the most part had a much more trainable labor force then we did.

The third point is what I call technology diffusion policy. That is to say, I think one of the most important areas for government intervention because, it is an area where I think there is a good deal of market failure, is in the promotion of the diffusion of new technologies. Such things as extension programs and information dissemination, etc. I think again speaking parochially for the U.S., our technology policy especially since the end of World War II has been what Henry Ergus of OECD, has characterized as a technology generation policy with almost no emphasis on diffusion, with the single important exception of agriculture. In the field of agriculture the federal investment in extension services to the farmers is just about equal in magnitude, to the federal part of the national investment in research and development. You contrast that with the situation, let's say in NASA, which advertises that it has a very strong technology extension policy. The expenditures compared with R&D are 0.1%. That is a ridiculous extension policy.

Let me just say one other thing about technology diffusion policy. I think a very important aspect of technology diffusion policy which I emphasized in my talk yesterday, in which our research has already indicated has great importance, is the promotion of linkages among firms particularly linkages between small firms and their customers, linkages between machinery vendors and small firms, and so on. Which is an area where there is a good deal of market failure. And this is where I think government does have a role.

Fourth, more general social and economic policies that promote the mobility of labor, let's say to reduce the risks of job changing and moving, and I want to mention two things here. Portable pensions, and some form of minimal at least national health care, so that people are not tied to their companies or to their localities through their health care insurance systems, and so on. It is interesting to notice that one of the difficulties that have occurred in the U.S., and I think the United States is probably the worst case example, has been that one of the largest cause in the shutting down of obsolete steel plants, for example in the U.S., has been the pension liability of the corresponding firms.

Fifth, standards promotion which could be regarded as a sub case of technology diffusion policy. I think one of the very striking examples of the importance of standards is the entry of Japan into the CNC small scale computerized machining business, because they succeeded in standardizing the controllers through the instrumentality of the company Fanuc, so that there was a great deal of compatibility of the software and hardware among the controllers, so that small plants and small firms could in fact adopt a technology very rapidly, because there wasn't a tremendous job in sorting out different incompatible standards.

The sixth item, is something that I think there has been a great deal of discussion of at this conference, and that is social and organizational research relating to the introduction of new technologies, particularly production technologies. I hope maybe one of the benefits of this research that has been done at IIASA, will be to show the importance of this. The only national government that I know that really invests a lot in this area, is that of Germany which has a number of centers doing very broad survey and case study research, looking in detail at the impact of this cluster of technologies which we have called CIM, in different types of firms and so on. I think there needs to be a great deal more research of that sort.

I think that this is important, in part, because I am somewhat sceptical of the ability to predict very much about the impact of new technologies, at least without a very strong base of empirical monitoring of what has actually been going on. And particularly on a longitudinal basis there is repeated surveys intervals to see how the situation is evolving in order to provide a basis for production and anticipation.

The seventh area for government intervention, which is much more controversial and I think has to be much more selective, is what I have labeled high risk generic research related to the technology. I think this has to be highly selective, with concentration on certain kinds of generic problems, generic software engineering for example and research to support standard setting, and to set out a basis for performance criteria for CIM equipment.

Finally my eighth point, something we talked about quite a bit this morning, incentives for long time horizon planning of investment in production technology. Here I wish I had more concrete suggestions to make because my own feeling is that the conventional wisdom theories, at least as current in the U.S., about would promote longer term incentives such as the cost of capital, and so on, I think have some importance but I think there is a more deeply cultural embeddedness to the short time horizons one has in the U.S. I think a great deal more research needs to be done on this subject.

This is just a very quick overview of a few areas where I think the attention of governments would be worthwhile. If it has been a little bit parochially biased in direction of the shortcomings of the U.S. it is partly because of my own experience and so on, but I think it has importance for all countries.

Implications for Industries

by

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CLOSING KEYNOTE SPEECHES

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"IMPLICATIONS FOR INDUSTRIES"

In this final summary I am going to talk about the implications of the IIASA project for Industry. During the past three days you have had at least a glimpse of the nature and comprehensiveness of the IIASA CIM project, the studies, and the kind of information which has been developed. But really of course you only have seen the tip of the iceberg and there is a tremendous, wonderful volume of information in four volumes, of course, but volume in the other sense of information and knowledge there, most of which has not been brought together in one place before. I think that that in itself is a major implication for industry now that they have such a tool as this. But let's go on and talk about the implications.

I think the basic implication is the one that was on the cover of the program you received before you came. The basic implication is that Computer Integrated Manufacturing is a revolution in progress. Technology, organization and people in progress. Why? Because CIM is not an improved methodology for carrying out conventional manufacturing. It is a wholly new approach to operating manufacturing in its entirety. That has tremendous implications for industry and they are only just beginning to realize the significance of that. And yet it is exactly what is happening. Because it is just a revolution in progress at this time. When the full force of that implication strikes industry it is going to be terrific. But it is starting to happen and we shall talk a little more about that in a moment. So a wholly new approach to operating in its entirety in technological, managerial, organizational, economical, and societal components of CIM.

To put other implications in perspective let's start by going back to CIM's roots very briefly and have a look at those. It essentially started to begin back in the 1950s with the advent of digital computer technology in the form of numerical controlled machine tools, that probably caught our attention as a potential of digital technology which became computer technology, of course. Its potential for manufacturing seemed to do something very unusual to manufacturing, at least one very small aspect of it at that time. But as we began to think about that and cogitated on it and say "what are the real implications" then we began to see something broader. And by the 1960s, I think we'd arrived at some precepts and concepts that gave some flavor at least of the broader implications of digital technology for manufacturing.

The first one, really was you might say a precept that revolved around the fact that we began to recognize that manufacturing is a system, it is not just a collection of bits and pieces of activities. And that the computer is a systems tool, and here was something then that could give us for the first time a real way, a real tool to operate manufacturing as a system. That led, of course, to the concepts of computer integrated manufacturing, a tool that could integrate the system of manufacturing and operate it as a system, a computer integrated manufacturing system. In addition, of course, this tool had some other very fine interesting characteristics for manufacturing. It showed capability for flexible automation of manufacturing, the first thing that happened was numerical control. But also it is an optimizing tool and it showed possibilities then for online optimization of the system of manufacturing, but most of all the potential for the overall integration of the total system of manufacturing.

Those are the things we begin to see were possible. But they were only concepts, of course. What happened, of course, looking at those concepts this was one way of picturing those concepts of CIM and the CIM systems that developed by the late 1960s. It is really just a technological system that has boxes indicating the various elements of manufacturing which usually had been operated more or less independently in the past and which now we could put together and operate as a system at least we felt we could, we saw a potential for that. It is interesting to note that basically the two major subsystems of that system are product design and production planning which include process planning and programming and that kind of thing is todays CAD/CAM subsystem.

Then, of course, the production control equipment and processes are todays FMS systems. The overall aim that we could see was for Flexible Automation of that system, online optimization, but most importantly integration of all that to operate it as a total system. We still haven't succeeded in integrating a whole system very well, we found that we could integrate the FMS part most thoroughly and this became the most sophisticated and well integrated part. In other words, sub-system of the total system of manufacturing in the form of FMS. It became more or less the focal point for understanding what integration could do.

CAD/CAM has had to struggle to become more and more of an integrated sub-system and the whole thing is having a lot of trouble. It is worth noting that though this is the technological system as conceived as the system at that time, at that time we also pointed out that the potential is not only technological for those three things but had real potential to free humans for creative work. So that became a part of the picture.

That was by the end of the 1960s. Then we moved along into the 70s and 80s and what happened? Well, unfortunately there was pretty slow progress of the CIM system concept and its possibilities for integration, automation and the optimization of the system of manufacturing. Why? All too many companies went down a blind alley because here was a new tool and they had a lot of fun playing with it and applying it to bits and pieces of manufacturing and getting what we call gee-whizz results. Look what it does here, gee-whizz, look what it does there, and so on. They were busy applying the computer to the bits and pieces of manufacturing and creating islands of automation. Not integrating the system at all. In fact, more often enough they were just blind to the benefits and possibilities of future integration of this system and so they really erected within their own operations barriers of incompatability. It was going to make it very difficult for them to integrate.

I think that a cooperative international project at that time which would have elucidated the technological, economic and social potential of CIM--similar to the present IIASA CIM Project--might well have helped save the day and moved us along more rapidly than we did move in those two decades. But things did begin to change and today we see a real change having taken place. It is evident, I find it throughout the world, that there is an overall international trend toward a realistic and substantial accomplishment of full CIM. At last industry has said: "Oh, yes, this is what it is all about. We better try and get into the act and do it." And that really began to become pronounced about 1985 which is just shortly before the IIASA project got underway.

At the same time an expanded concept of CIM developed, realizing that it is not just a technological system and this was certainly an important occurrence or finding tool, that was documented in 1985 quite well I think, by the Computer and Automated Systems Association of the Society of Manufacturing Engineers (CASA). They documented, at a fairly early stage, a technological system, but by 1985 they were documenting the realization that a CIM system is far more than a technological system alone. It must integrate with finance, manufacturing management and human resource management most importantly right in the forefront of the picture were marketing, strategic planning, business financial and human factor elements of the manufacturing enterprise. A combination of those two things is, I think, what has helped us toward this commitment.

There is an overall international trend in this commitment on the part of industry toward realistic and substantial accomplishment of full CIM. And that is what is strongly taking hold today throughout the world. I believe that IIASA's CIM project has been an important factor in really stimulating and helping this awakening and commitment of world industries to the implementation of CIM, to help it really get going and get momentum and understanding. Even though, of course, it was a project in process that was already information coming out, here was an international organization of high prestige making a major study in this area to bring the information together and gradually this began to feed in to industry, and began to help them in their commitment, in really establishing this committment, to moving into full Computer Integration.

Now the study is completed, of course, essentially, and at least the initial study, the completion of the initial study. That comes, I think, then at a very opportune time because it has coincided with this awakening and commitment of industry to CIM. It now is in a position as it becomes fully documented and disseminated, diffused, the findings of the study provide substantial help, guidance, and incentive to industry for successful accomplishment of such implementation.

Let's get a little more specific about implications now. The completed study provides a tremendous wealth of understanding of the technological, economic and social realities and consequences of the emerging new industrial revolution as spawned by CIM. It is in a form that is readily absorbable by industry. It is written and presented, and was developed, in a form that could be understood and used by industry. Because it documents powerful strategic benefits which CIM has already been able to demonstrate in practice. And it provides understanding which industry can apply to plan and develop and implement effective and successful CIM. And in particular, harking back to what I was talking about on Monday, I think that the monumental FMS database and study and analysis in particular will be of tremendous benefit to industry, both for understanding the significance of this technology, and for strategic planning of its utilization.

One of the particular monuments of the study. If we look at the findings or conclusions that have come out of the IIASA CIM Project, and look at those that would be of principal or would have major implications for industry, look at the principal conclusions and select those that might have particular major implications for industry, each of which is well documented in the study, then we see things such as the conclusion that productivity of capital and labor will increase sharply in the 1990s in countries using CIM effectively. Once industry knows that and sees it well documented, the implications are obvious to it, CIM has to be utilised. I am talking about individual industrial companies. Competitiveness in manufacturing will increasingly depend on the quality of a firm's integration software. It tells them were to point their efforts if they are going to be really competitive. It focusses them in, it homes them in on CIM.

The software component of capital investment in manufacturing will continue to grow in importance relative to the hardware component. Something difficult for many companies to face up to. Here it says it in so many words and it documents the fact that that is the case.

A specific finding, is that it is very difficult to convert Taylorist-Fordist manufacturing plants to CIM by merely installing CIM hardware and software. Of course, you could say also that its difficult to convert any manufacturing enterprise to CIM by merely installing hardware and software, but the point is that it is particularly difficult for Taylorist-Fordist manufacturing plants to do that. That has a real message for those companies that have gone strongly down the Taylorist-Fordist path.

Under the impact of increased flexibility and economies of scope provided by CIM, a trend is developing toward more dispersed, decentralized production systems in industrialized countries. Now I have stated that as a positive finding . It is not stated that way, I did it for brevity here. It is a likely occurrence. It is not something that is clearly black and white in the report, because there are various points of view about that. But it does seem to be that this is more likely than not the situation.

Then I think, a very important kind of finding, others are well related to the technological aspects, but this is something more. Good sound CIM technology is only a necessary condition for success, not a sufficient condition. It must be accompanied by good, sound systems oriented approach to human factors. Human factors in a broad sense that Brooks referred to. Such as: well trained labor, participative team approaches, within and between management and labor, the opportunity for satisfying, creative work, understanding of the manufacturing system at all levels in the organization, and the need therefore for generalists, and systems integrators, and manufacturing strategists with systems views.

A culture of cooperative relationships, integrated, in other words, non-compartmented organization, those kinds of things related to human factors. And we have heard quite a lot about this in these three days. Most of the people, in one way or another, have come back to this point in one form or another. And it has even been pointed out that up to 80% of the benefits of CIM can come via this component of the CIM system. The human factors component of the CIM system can in some cases provide up to or make possible up to 80% of the benefits of a CIM enterprise.

I think that such conclusions as these combined with the wealth of related detailed findings of the overall IIASA study, serve fair warning to the manufacturing industries of the world that a revolutionary, wholly new way of operating a manufacturing enterprise, be it large or small, a way offering powerful, strategic and competitive advantages to such enterprises, is now coming into being and already beginning to demonstrate that kind of power.

Those manufacturing enterprises and industries which fail to heed that warning, and to institute appropriate action to take full advantage of this new approach, to manufacturing will to say the least, be operating at an increasingly severe disadvantage as this irreversible revolution which is now entering its period of most rapid growth, rolls ahead. Those companies, those manufacturing organizations which do heed this warning and take action accordingly, can find in the results of the IIASA CIM Project, substantial guidance and help in support of their efforts to achieve that kind of advantage.

Now, let's wind up by taking somewhat of a look ahead. Iouri Tchijov's forecast of the future of CIM technology, and using FMS as the most advanced form of integrated manufacturing that really is wholly realized today, as the measure of that. He forecasts diffusion curves and here in 1990, it looks as though the inflexion point is somewhere up around the year 2000, however, as Tchijov himself says, he doesn't really trust the inflexion point being that close at the early stage that we are here. Diffusion theory would say that that is how it is going to go.

But anyhow, what about the future and IIASA's role in it? We have Tchijov's forecasts based on FMS as the most fully integrated sub-system of CIM today, he used that as a basis for forecasting future trends. He anticipated we are fast approaching an apparent inflexion point, which may well be a moving inflexion point.

I think that gives a mandate to IIASA. It must not abandon its role as the pathfinder for the road to continual improvement in manufacturing performance which it has won at this critical time. We are really on the upgrade and racing toward some inflexion point. We need good strong support at this particular time when industry is getting on board the CIM bandwagon. I think an ongoing program appropriate to that role is a must.