Technological preconditions for skilled production work in computer integrated manufacturing: expertise on behalf of the Institut Arbeit und Technik, Gelsenkirchen, as part of the FAST-project "Prospects of Anthropocentric Production Systems"

Hirsch-Kreinsen, Hartmut; Köhler, Christoph; Moldaschl, Manfred; Schultz-Wild, Rainer

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Forecasting and Assessment
in Science and Technology

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PREFACE

Since the mid 1970's industry in Europe has performed less well in comparison with the USA and especially compared to Japan. Europe has also lost ground in basic research where its spending on R & D (as a percentage of GDP) is below both the USA and Japan. However, the completion of the single market by the end of 1992 and the future prospect of an enlarged Community of EC16, or 18+ by the 21st century offers the potential for a resurgence in European manufacturing. Collectively, the papers in this series demonstrate how anthropocentric production systems can fulfill this potential. Based upon extensive research on the various sectors and regions of European manufacturing, the different reports converge towards a common conclusion: that reliance upon technology alone is an inadequate response to the challanges of world markets in the future; that successful modernisation of European industry depends upon its most valuable resource - human skills and creativity.

This report is part of a publication series presenting the results of FAST research on the "prospects and conditions for anthropocentric production systems in Europe by the 21st Century". The research was sponsored by the European Commission MONITOR - FAST Programme, 1989-1992 and generously co-funded by the government of Nordrhein Westfalen in the Federal Republic of Germany. Research teams from all countries of the European Community participated in the project, as well as researchers from the USA, Japan and Australia. More than twenty reports are available or in the process of publication providing a comprehensive and comparative assessment of the human aspects of advanced manufacturing in Europe.

All of the studies in the series address the general issue of defining anthropocentric production systems: national research traditions and manufacturing experience in the various member states have produced different interpretations of anthropocentric production systems; this is regarded as a strength not a weakness of European manufacturing in the sense that European diversity suggests a number of possible trajectories of change in manufacturing in response to world competition in the 1990's rather than a unilinear path of development, or an assumption that there is "one best way" of managing technological change. A central feature of the research was close collaboration between the research teams and workshop discussions: this helped to identify a common minimal definition of anthropocentric production systems and a common analytical framework for country comparisons without the straitjacket of a predetermined research schema which would have lacked sensitivity to cultural differences in Europe.

APS can be defined as advanced manufacturing based on the optimal utilisation of skilled human resoures, collaborative industrial organisation and adapted technologies. All the reports in the series explore the concept of APS in some detail, especially the general reports by Werner Wobbe - series no. 1, Paul Kidd - series no. 3 and Franz Lehner - series no. 4.

The reports comprise the research results of four networks:

The first - country studies co-ordinated by the Institut Arbeit Technik, Gelsenkirchen. It included social scientists from the member states who are to investigate the socioeconomic factors which affect the prospects and conditions for APS by the early 21st Century. This included, in addition, a synthesis report, comparing the research results from the various member states (Franz Lehner, Report no. 4) and special consideration of the less industrialized member states (coordinated by Sean O'Siochru, NEXUS, Ireland: Report no. 6).

Secondly, a Technical Recommendations Network, coordinated by P. Kidd (Cheshire - Henbury), comprising technical experts, who addressed the interface between the technical features of advanced manufacturing and human resources in order to identify future research priorities for the European Commission (Report no.3).

A third network, coordinated by D. Brandt (HDZ, Aachen), undertook a survey of case studies of the application of APS in the member states (Report no. 2).

Fourthly, the CAPIRN Network (Culture and Production International Research Network) coordinated by Felix Rauner (Bremen) and Richard Gordon (Santa Cruz), reports on the results of an international project on production cultures, comparing Europe with Japan, USA, and Australia and situating its analysis in the context of Anthropocentric Production Systems.

The series also includes a number of related studies of specific issues concerning the implications of APS for technology design.

Tony Charles & Werner Wobbe - FAST
June 1991

INSTITUT FÜR SOZIALWISSENSCHAFTLICHE FORSCHUNG E.V. - ISF MÜNCHEN

HARTMUT HIRSCH-KREINSEN, CHRISTOPH KÖHLER,
MANFRED MOLDASCHL, RAINER SCHULTZ-WILD

TECHNOLOGICAL PRECONDITIONS FOR SKILLED PRODUCTION WORK IN COMPUTER INTEGRATED MANUFACTURING

Expertise on behalf of the *Institut Arbeit und Technik*, Gelsenkirchen,
as part of the FAST-project *"Prospects of Anthropocentric Production Systems"*

Munich, May 1991

Summary:

Technological Preconditions for Skilled Production Work

In West Germany the process of automation in the engineering industries is characterized by an advancing diffusion of computer integrated manufacturing components and systems (CIM) and is showing a tendency towards increasing dynamic. This applies particularly for small and medium-sized metal-working companies, whereas larger ones already show higher rates of applications of computer systems.

At present, no clearly predominant concept of restructuring industrial work has emerged. To simplify matters, there are three different models of work on the shop floor: *computer aided "Neo-Taylorism"*, *polarized production work* and *skilled and cooperative production work*. While some companies are attempting to make traditional Tayloristic forms of work organization more efficient by utilizing more computer-based technologies, others are seeking ways and means of maintaining or revitalizing forms of skilled production work on the shop-floor.

According to practical experience to date, as well as in the opinion of many experts, only forms of work organization which are oriented to concepts of skilled production work will be able to offer sufficient chances not only for efficient manufacturing, but also for ensuring the availability of skilled labour for industry in the long run. This development option may therefore be regarded as a *guide-line* for work organization for large sectors of the metal-working industry. As a result of a significant reduction of the mostly distinct division of labour in the dimensions of hierarchy, skills, and functions, this model seeks to create work structures which are characterized by a high level of skills of all workers, mutual interchangeability of tasks and jobs, as well as self-coordination and cooperation within work groups. However, whether or not this concept will be able to establish itself as a more or less general industrial practice depends on certain preconditions.

One major factor is the selection and utilization of technological systems which support forms of skilled production work or at least do not obstruct or prevent them. The relationship between technology and work organization which we have attempted to outline, will continue to play an important role in the ongoing and future changes in industrial work and structures of industrial labour.

A crucial prerequisite for skilled production work is the further development and utilization of computer systems which are flexible with respect to work organization and are open for adaptation to shop-floor conditions. These systems offer the largest possible scope for (re)-integrating conception and execu-

tion; this is particularly relevant in respect to CAD/CAM and PPC systems which are directly correlated with the existing hierarchical and functional division of labour in companies and thus with the associated separation or integration of conception and execution. It may be differentiated between two fundamentally different technology concepts:

- first, systems which entail the stabilization of or even an increase in the traditional forms of organization based on a high degree of division of labour;

- second, undetermined system concepts which offer a high degree of flexibility with regard to work organization and by a specific design enable them to be utilized in the offices of planning or production engineering departments as well as on the shop-floor.

The paper presents results of our analysis in respect of this dichotomy with regard to various CIM components and systems on the market; special consideration is given to FMS, their components and peripherals, to manufacturing control systems and electronic control stations in particular, as well as to DNC and CAD-NC systems.

While the various types of CIM components on the market and in use do not necessarily *determine* the actual forms of work organization and work design, they must nevertheless be regarded as important factors which may either facilitate or obstruct the establishment of skilled production work.

The type of company implementation process of CIM technologies, the way in which innovations in regard to technology and organization are managed, are other factors having a decisive effect on the chances for skilled production work. Whereas mere reactive manpower policies mean severe risks for productivity as well as the quality of working life in the long run, a strategy which is geared to the option of skilled and cooperative production work involves long term manpower planning including further training policies. While an increasing number of industrial companies in the Federal Republic would seem to be taking initial steps in this direction, it cannot, at present, be termed as the mainstream of development in industrial labour.

Content

I. Introduction

1. CIM and the Factory of the Future

(1) Many observers agree that new types of rationalization strategies and a change in modernization policy have emerged in West German industries since the 1980s. Stagnating economic growth and fiercer competition on national and international markets call for higher levels of productivity and a more flexible production if customers' demands are to be met.

The rapid pace of development in microelectronics and information technology promises that the technical resources to attain a new level of optimization between high productivity and high flexibility, which have been contradictory goals up until now, are now available. Significant changes can be expected in more and more areas where the new computer-aided and computer-integrated technologies such as CAD, CAM, FMS and PPC are employed. Due to the system character of these technologies, accompanying rationalization patterns are supposed to be both far-reaching and of a "systemic" nature (Sauer et al. 1991).

Judging by the general opinion among engineers, managers, and industrialists, the new computer-based technologies will probably establish themselves quite quickly since they promise to solve the current problems of industry and allow for new forms of technical integration on the shop-floor and on the factory level.

However, the results of our survey (Schultz-Wild et al. 1989; Schultz-Wild 1991b) indicate that the diffusion of the new technologies progresses much slower than was predicted by their advocates. This can be attributed to their high costs, high implementation risks, technical problems with interfaces between components in both hard- and software, and various other reasons. On the other hand, our observations suggest that now, in the early 1990s, many companies are on the verge of introducing new computer systems in the fields of production planning and control (PPC), some of them for the first time, and that there will also be an increase in the number of interfaces integrating various process planning and control components (CAD/CAM). The trend definitely seems to be moving in the direction of more complex CIM systems. All in all, a very dynamic development can be observed in the field of production-related computer applications.

(2) In the meantime it is widely agreed among experts that the concept of the highly automated "unmanned" factory will find only very limited applications in Europe within the near future and that this concept is at best suitable only for specific areas of highly standardized mass production.

There is also a growing body of opinion stressing the limitations of the long-prevailing Tayloristic or Fordistic model of manufacturing organization and work structuring (cf. e.g. Piore, Sabel 1984; Brödner 1985; Warnecke 1985). This rationalization pattern is based on a distinct division of labour and job specialization on the shop-floor, and means centralized planning and decision-making. Tayloristic rationalization was particularly important for large industries and mass production during the 1960s and early 1970s in order to overcome manpower shortages in an expanding economy. This type of rationalization strategy has not only dominated in mass production industries in the Federal Republic of Germany but has also been an important guide-line for mechanical engineering industries, characterized by customized and small-batch manufacturing of complex products.

(3) Many experts believe that the essential preconditions for competitive factory structures in the future will not only consist of computer utilization and more and more computer integration in manufacturing (CIM), but also of skilled, qualified manpower (cf. Warner et al. 1990). "New production concepts" (Kern, Schumann 1984), and new factory structures are being advocated which take advantage of the existing skills and qualifications and which seek to secure the potential for innovation and the abilities in adaptation, particularly in the case of the often smaller and medium-sized companies, by keeping the scope for taking action and decision making close to the basis of the manufacturing process, on the shop-floor. In the long run, it will only be possible to utilize the potential for flexibility and productivity offered by the new manufacturing technology through skilled workers. Skilled and cooperative work within production islands on the shop-floor is often mentioned in this context as an effective way to reintegrate and reorganize tasks and functions.

The points mentioned above are the main reasons why some companies are interested in reversing traditional Tayloristic rationalization strategies (geared to distinct forms of division of labour and job specialization). These companies want to take advantage of their skilled and qualified work force familiar with the special requirements of flexible automation and employ these workers on manufacturing equipment which is becoming more and more complex. But there are certain disadvantages and barriers when it comes to introducing skill-based work systems. One is certainly the higher training and implementation costs if so far there are mainly semi-skilled production workers occupied; another one is the scarce availability of suitable technical components and systems.

(4) It is often assumed that technological innovations will more or less automatically lead to an increase in the demand for skilled workers. Yet this trend has not yet become apparent (Köhler, Schmierl 1991). The risk still exists that skilled work will be undermined if tasks requiring skills are limited through automation and centralistic organization. This undermining of skilled production work could threaten the flexibility and quality of manufacturing, which has played a key role in the success of the German mechanical engineering industries. This does not have to be the case, however, if rationalization strategies and implementation processes of new technologies utilize opportunities for supporting the structures of skilled production work.

(5) It is certainly not technology alone which determines the impact computer-aided systems have on the organization of work and the structures of industrial labour. The way this technology is configured and implemented must be regarded as an important factor in this respect, however.

The spectrum of *technical components* on the market for computer-aided integration has increased considerably. This holds true for design and process planning functions (CAD, CAP), for production planning and control (PPC), for manufacturing functions of machine control, tool management, work-piece handling and transport (CAM) as well as quality assurance (CAQ). Any complete CIM packages with fully integrated computer systems for whole factories have been scarcely available so far.

CIM components, systems, and concepts can either create scope for innovating the organization of work or restrict the possible alternatives for a company. CIM components on the market can be classified into:

- those based on strongly centralized concepts which aim at a distinct division between conception and execution, i.e. between the functions of planning, control, and monitoring in planning departments, and work executed on the shop-floor, and

- those which are more open and flexible in regard to different types of manufacturing organization and work structuring.

(6) This paper[1] attempts to provide information on this dichotomy with regard to various FMS, PPC and CAD/CAM systems. The following assumptions are based primarily on the findings provided by a survey and by case studies conducted by the Institute for Social Research (ISF Munich). These research projects deal with the scope for design with respect to work organization and skilled labour when CIM technologies (FMS, PPC, CAD/CAM) were introduced

1 The authors want to express their special appreciation to Dipl.Ing. Eckehard Moritz for his numerous suggestions and helpful assistance in completing this paper.

into West German mechanical engineering industries (Schultz-Wild et al. 1989; Hirsch-Kreinsen et al. 1990; v. Behr, Köhler 1990; Chapter III in Altmann et al. 1991).

2. Alternatives for Industrial Labour

Our findings indicate that the implementation of computer-integrated components and systems generally has no massive direct impact on work organization. However, there are several associated factors, both inside the company and external ones, which suggest that there is a broad spectrum of possible developments in the area of manpower policies in the future.

The interaction of these and other factors does not compel company strategies in regard to work organization to move into any specific direction. On the contrary, there are many different ways industrial manpower strategies may develop; three basic types may be identified.

(1) The first alternative can be defined as a concept of "*skilled and cooperative production work*" (Fig. 1.01). This concept is based on a considerable reduction in the division of labour and presupposes the existence of a work force of qualified workers with skills of a relatively homogeneous level. In this model, workers get assigned a whole package of various planning, monitoring, and operational tasks and functions ranging from process planning and programming to actual feeding and maintaining of the machine tools. The execution of these tasks is based on the principles of self-determination and cooperation. The concept of skilled and cooperative production work has been most widely implemented in the various forms of *group work*. Such work groups, e.g. system operators in a flexible manufacturing system, are able to work fairly autonomously. Sometimes these groups are integrated into the superordinate functional context of the manufacturing process according to the black box principle, i.e. as a semi-autonomous "plant within a plant" (Everitt 1985).

While, especially in view of the increasing flexibility demanded by the diversification of market needs, there is good reason to assume that industrial work organized on the basis of skills is the only form which will be able to guarantee long-term economic efficiency in certain types of production (high quality, small series, complex products), it remains doubtful that this type of work will establish itself as the main trend, bearing in mind the current and foreseeable future conditions. Two possible obstacles are:

- problems with the supply of skilled and qualified production workers for industrial jobs on the labour market; and
- the lack of technical components and systems to accommodate such forms of work.

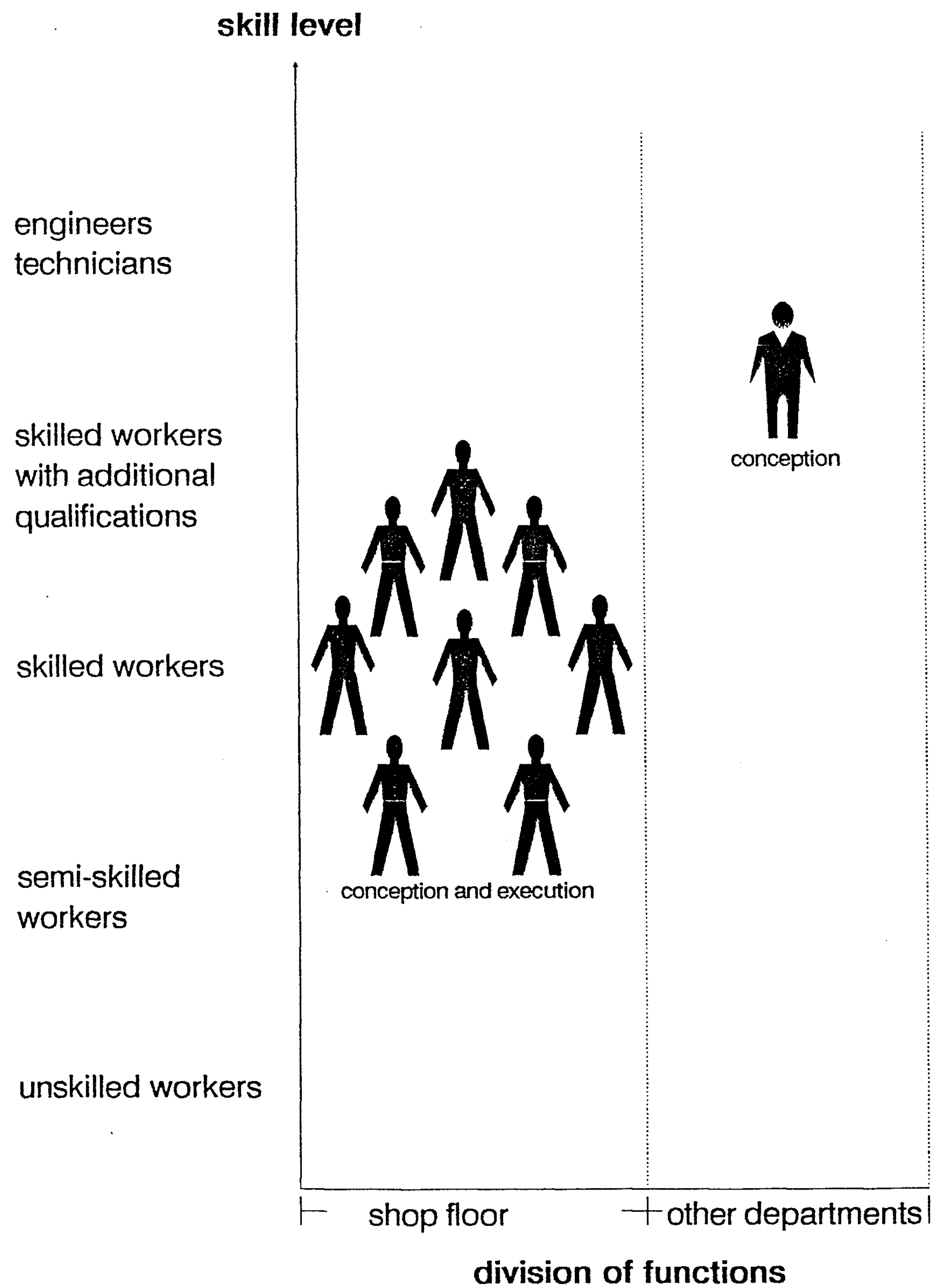

Figure 1.01	Skilled and Cooperative Production Work	ISF 1991

Other obstacles created by specific company structures should not be underestimated: e.g. the risks involved in abandoning well-established organizational structures and the associated shift from the established balance of power and interest constellations, and the extent of additional expenditure due to the necessary reorganization and further training.

(2) Unfavourable circumstances like those mentioned above may foster an alternative which may be termed "*computer-aided Neo-Taylorism*" (Fig. 1.02). Its central feature is the further development and efficient enhancement of the hierarchical, functional and skill-related division of labour. Planning, programming, and scheduling are carried out exclusively by engineering departments. Service functions such as maintenance, repair, quality assurance and the management of equipment are systematically removed from the shop-floor and handled by specially trained skilled workers and technicians. The functions which remain on the shop-floor are those directly related to the actual manufacturing process such as machine setting, work-piece handling and machine monitoring. Even these mainly manual tasks are as far as possible dealt with by specialized workers in hierarchically graded jobs. To perform these functions requires nothing more than a rudimentary aptitude and the will to endure routine work.

Should this development find general acceptance, it will certainly be accompanied by a long term reduction in the level of performance and profitability due to the fact that sales markets are becoming more and more turbulent and thus demand more flexibility. On the other hand, the computer-based capacity of neo-Tayloristic structures should not be ignored as a means to neutralize the objective pressure to bring about changes in the long run.

(3) There is yet another feasible development path which may be termed "*polarized production work*" (Fig. 1.03). Strategies of work design of this alternative take advantage of the obvious gains in efficiency associated with even a partial reintegration of planning, conception, and execution into the actual line of tasks performed on the shop-floor. In this concept, planning jobs in the manufacturing area are not done by skilled or especially trained shop-floor workers but rather by personnel with an educational background similar to that of technicians or engineers.

On the basis of production systems designed along these lines, such personnel holds new key positions in the manufacturing process, at central and complex shop-floor control stations, managing for example the control and monitoring of entire manufacturing sections, or supervising and controlling flexible manufacturing systems (FMS). These are positions which have a large scope for decision-making and taking autonomous action. The functions left for shop-floor workers are - like with the Neo-Tayloristic concept - reduced to simple manual tasks which can be dealt with by semi-skilled or even unskilled workers.

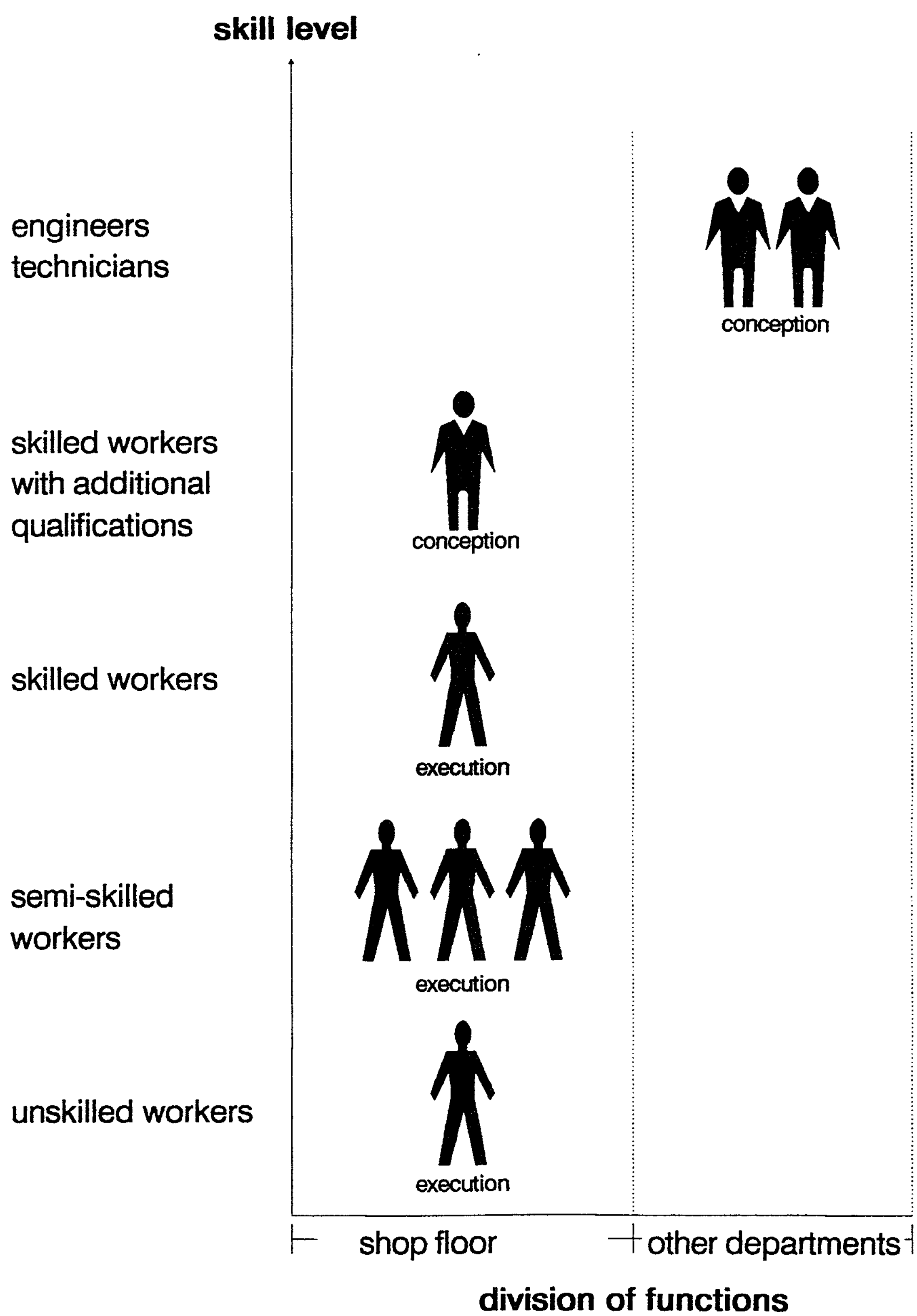

Figure 1.02	Computer-aided Neo-Taylorism	ISF 1991

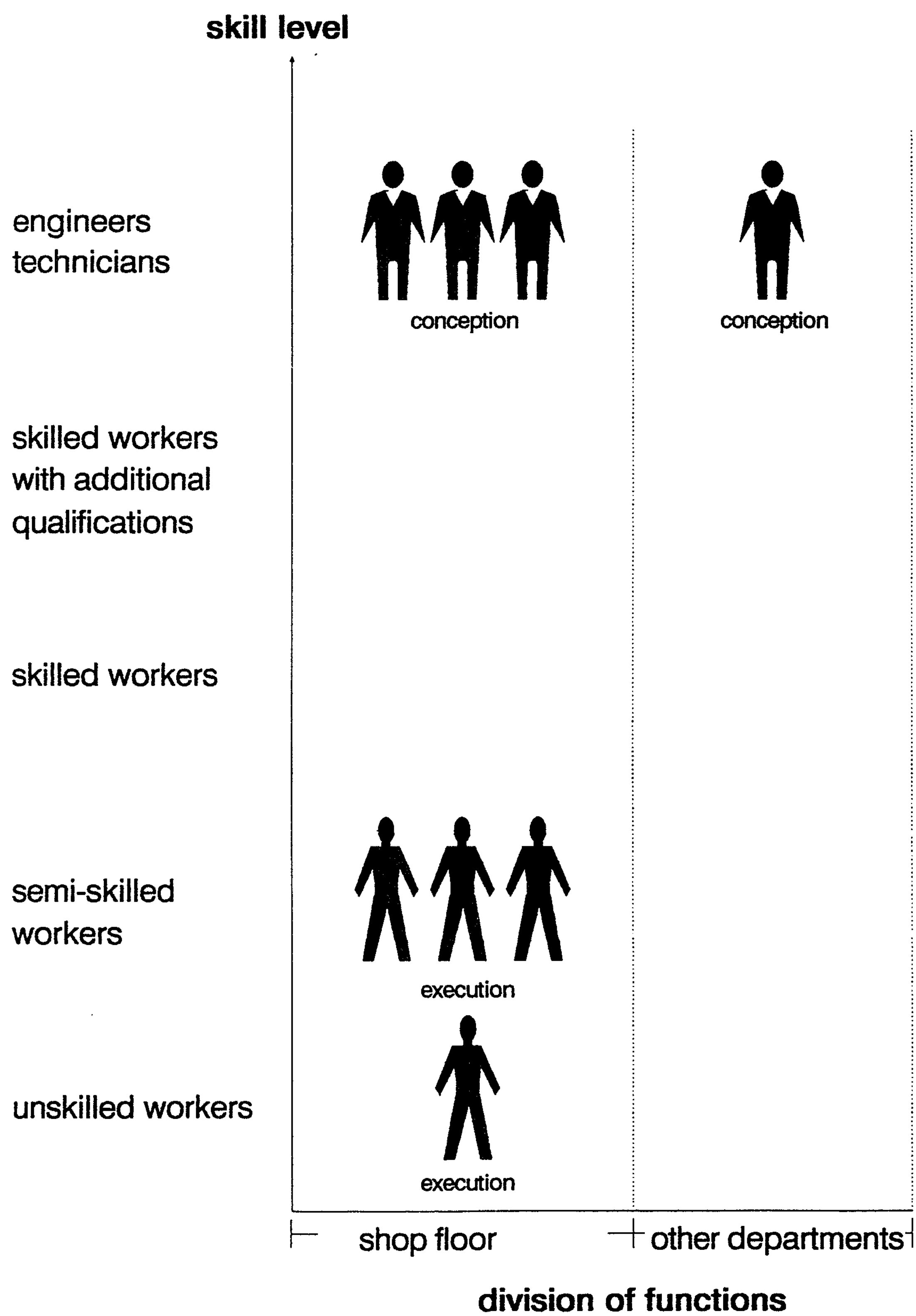

Figure 1.03	Polarized Production Work	ISF 1991

This option would seem to have a considerable chance of finding acceptance particularly in comparison with skill-based and cooperative production work. There are significant benefits with regard to flexibility and efficiency through a partial reorganization of the functional division of labour, while the risks of departing too far from the evolved and established company structures can be avoided. Although this option is a highly problematic one in terms of social implications and social policies, it offers highly attractive developmental perspectives for many companies. Moreover, many companies feel that they can acquire the personnel required for the comparatively low number of key shop-floor positions.

The following chapters attempt to analyze how technology supports or impedes the development of work organization and structures of industrial labour in one or another of the directions mentioned above. We are approaching these questions by examining three lines of technology: flexible manufacturing systems (II.), systems of production planning and control (III.) and the integration of CAD and CAM (IV.).

II. Flexible Manufacturing Systems - Design Possibilities Re-examined

Flexible manufacturing systems (FMS) cover a whole spectrum of technologies: machining, material flow, scheduling, and control technologies. They comprise elements of both integration paths: the "horizontal" planning and control of orders and production flow (via PPC systems etc.) as well as the "vertical" planning and control of production from design and programming, to machining and quality assurance (via CAD/CAM systems), which are examined more closely in Chapters III and IV, respectively. In an increasing number of cases FMS are also linked externally to superordinate control systems. FMS can be described as a highly advanced "small-scale CIM" - production and organization technology in one system. Both control technologies are important for determining the scope and limitations of factory and work organization.

1. FMS as Office-oriented Automation

The core element and technological basis of any FMS is the CNC machine tool. In the 1960s and 1970s, triggered by the advances in the numerical control technology, manufacturers producing customized and small-batch goods managed to narrow the productivity gap to large-scale production and to increase the degree of automation in machining processes. Efforts were directed towards automating the periphery of machine tools (rotating tables, turner heads, tool and pallet changers). With the introduction of FMS, the main objective followed by nine out of ten companies was to increase productivity.[2] This objective should be achieved without any loss in flexibility. Even though only a small portion of users (approx. 11% - mostly large-scale manufacturers) introduce FMS primarily with the intention of increasing flexibility, this objective has high priority among other users as well. In this context FMS may also be considered as an *automation-oriented* concept to achieve flexibility - in contrast to flexible production islands with their organization-oriented approach.

As empirical studies on work organization and the integration of FMS in the organization of production indicate (Fix-Sterz et al. 1990; Moldaschl, Weber 1986a), this automation concept is bound up with organizational structures characterized by a more or less strong division of labour between planning departments and the shop-floor. Basically, two factors can be used to explain this finding:

2 Cf. Fix-Sterz et al. 1987, p. 11. Data on the diffusion of FMS and forms of work organization are mainly based on an empirical survey conducted by the Fraunhofer-Institut für Systemtechnik und Innovationsforschung (ISI), Karlsruhe and ISF Munich in the autumn of 1985 (ISI/ISF study - cf. also Fix-Sterz et al. 1990). More recent wide-scale surveys on the application of FMS in the Federal Republic of Germany have not been published to date apart from a few system overviews and comparative surveys (e.g. Shah 1987; Primrose, Brown 1987; Hausknecht 1988; Eversheim et al. 1989; Hänsel et al. 1989).

- FMS demand a degree of investment in hardware, planning and implementation which far exceeds that required for the corresponding number of individual machine tools (whose share of the overall costs on average is only about 45%;[3] Fig. 2.01). The profitability of such an investment presupposes that a very high degree of utilization (usually over 80%) will be attained. In order to achieve this target, the technical staff endeavours to reduce the influence of contingencies, carelessness, and maloperation by automating the systems as extensively as possible (minimizing idle times by means of automatic planning, coordinating, and monitoring of the system internal procedures).

- FMS are generally far from achieving the ideal of the complete manufacturing of work-pieces. On average, only about 60% of the operations are carried out within the FMS (Eversheim, Schönheit 1989). For this reason, the coordinating of FMS operations with previous and following manufacturing steps is crucial. In view of management, this cannot be done by system operators without increased risks of mismatching and longer idle times.

The fact that a high degree of division of labour between the planning departments and the shop-floor is typical for most FMS cases cannot be seen as a result of technological determination. It is more the capital intensity and the sensitivity of the logistic FMS integration in job shop manufacturing which promote an office-oriented configuration and application. A few installations demonstrate that FMS do not necessarily implicate a centralistic concept of organization (Schultz-Wild et al. 1986; Herzog 1986; Roth 1988; v. Behr et al. 1991).

In the context of the technical realization on the one hand and the scope for different forms of work organization on the other, FMS, unlike systems used in planning and control like CAD/CAM or PPC, can hardly be classified into fundamental system alternatives. FMS combine several components and control systems which may be evaluated according to whether and to what extent they promote or impede shop-floor- and skilled worker-oriented forms of work organization. This has not only to refer to the "vertical" division between functions dealt within the FMS or other departments, but also to the "horizontal" division of labour within the FMS crew (Section 3). But, first of all, some empirical findings on development lines of FMS technology and work organization should be outlined.

3 Compared with much higher costs that were cited, the figures on installation costs seem relatively low; this is because the direct installation costs but not the total implementation costs were included in the evaluation.

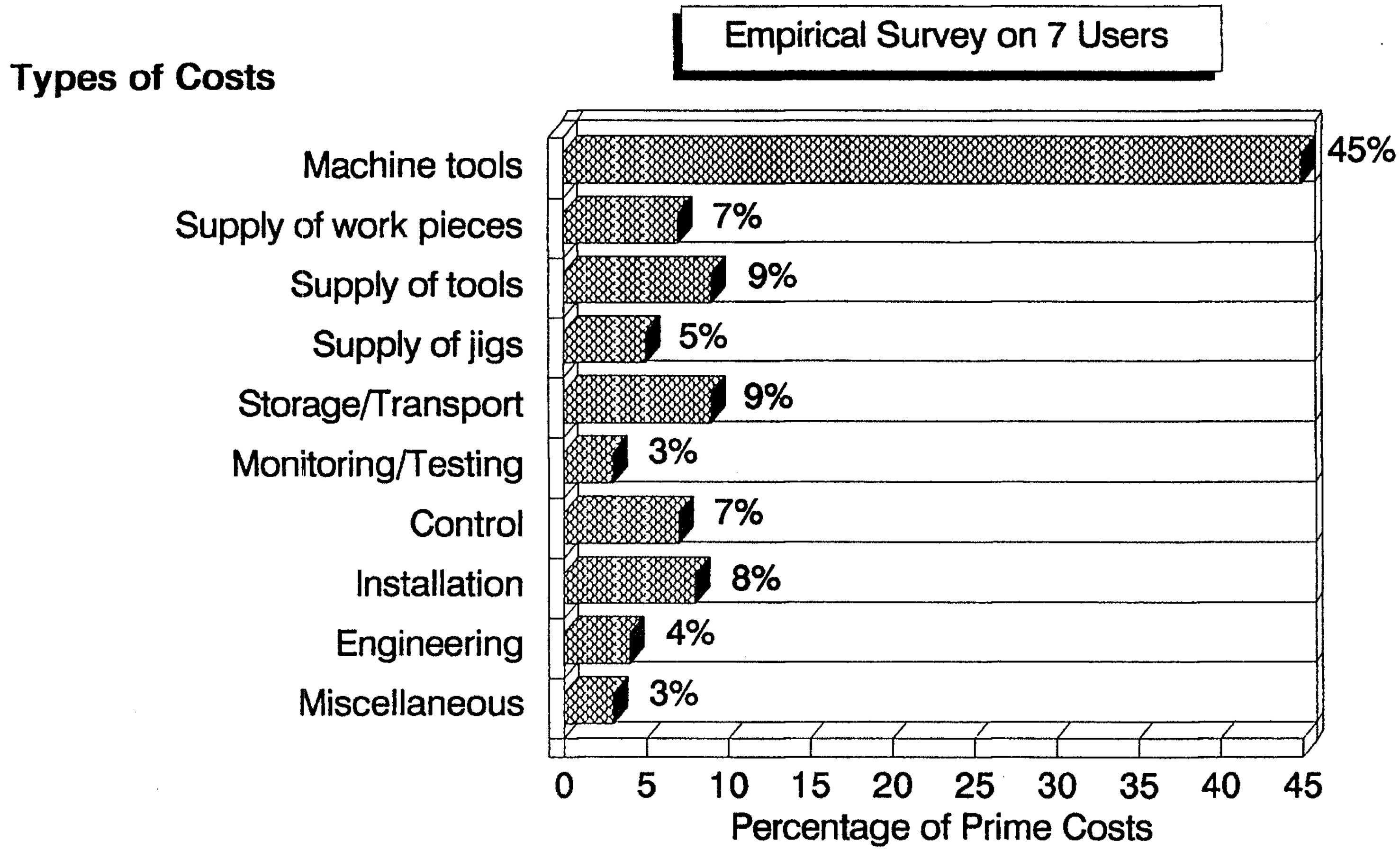

Figure 2.01	**Distribution of Direct Investment Costs** (according to Eversheim et al. 1989)	**ISF 1991**

2. Technical Concepts and Work Organization

For a long time the diffusion of FMS lagged far behind expectations and prognoses. Basically this was a result of the enormous planning, implementation, and investment costs and the fact that it is hard to prove their economic advantages. A marked increase in diffusion in the 1980s (Fig. 2.02) was triggered by the growing supply of standardized components and systems. This increase was clearly based on the one- and two-machine systems which were the easiest to standardize. This was likewise the reason for the reverse effect: the stagnation in the application of large systems with more than five machine tools, which require an average of ten(!) man-years for conceptualization and implementation (Shah 1987). Despite these enormous efforts, there were and are many problems even just mastering the (software) problems of the system control. Although some large systems with up to 33 machines were also implemented (e.g. Slickers 1988), the "philosophy" of employing large systems has not yet gained wide acceptance (e.g Kochan 1988; Childs 1989). Stand-alone, highly productive machining centres have proven to be more advantageous in practically all dimensions of flexibility (machining, set-up, retooling, etc.).

From a quantitative viewpoint, only one of the two basic FMS concepts succeeded to date, namely the one consisting of machine tools of the same type which can *replace* each other. FMS with different, *supplementary* machines designed to handle the complete machining of work-pieces and therefore necessitating a larger system size have remained isolated solutions in individual companies (e.g. Erkes et al. 1988; Schönheit, Wiegershaus 1989). The complexity of material flow organization (tools, work-pieces) and the problem of differing machining times are two of the factors which so far have obstructed the availability of standardized FMS solutions involving various machining methods.

So far, however, the machining concept may have an influence on the degree of the "vertical" division of labour because planning and scheduling functions are easier to centralize or even automate in FMS with replaceable machine tools.

The *size* of the system can have an impact both on the vertical as well as on the horizontal division of labour. On the whole, the larger the system and consequently, the larger the group working with it, the larger the scope for work organization in both directions:

- A single operator, responsible for a production cell or a two-machine system, is hardly able to assume planning and scheduling tasks to any considerable degree because of the time structure of necessary manual operations (machine-setting, chucking, handling breakdowns; cf. Section 4). This situation improves as soon as there are two or more workers in an FMS (Moldaschl, Weber 1986b).

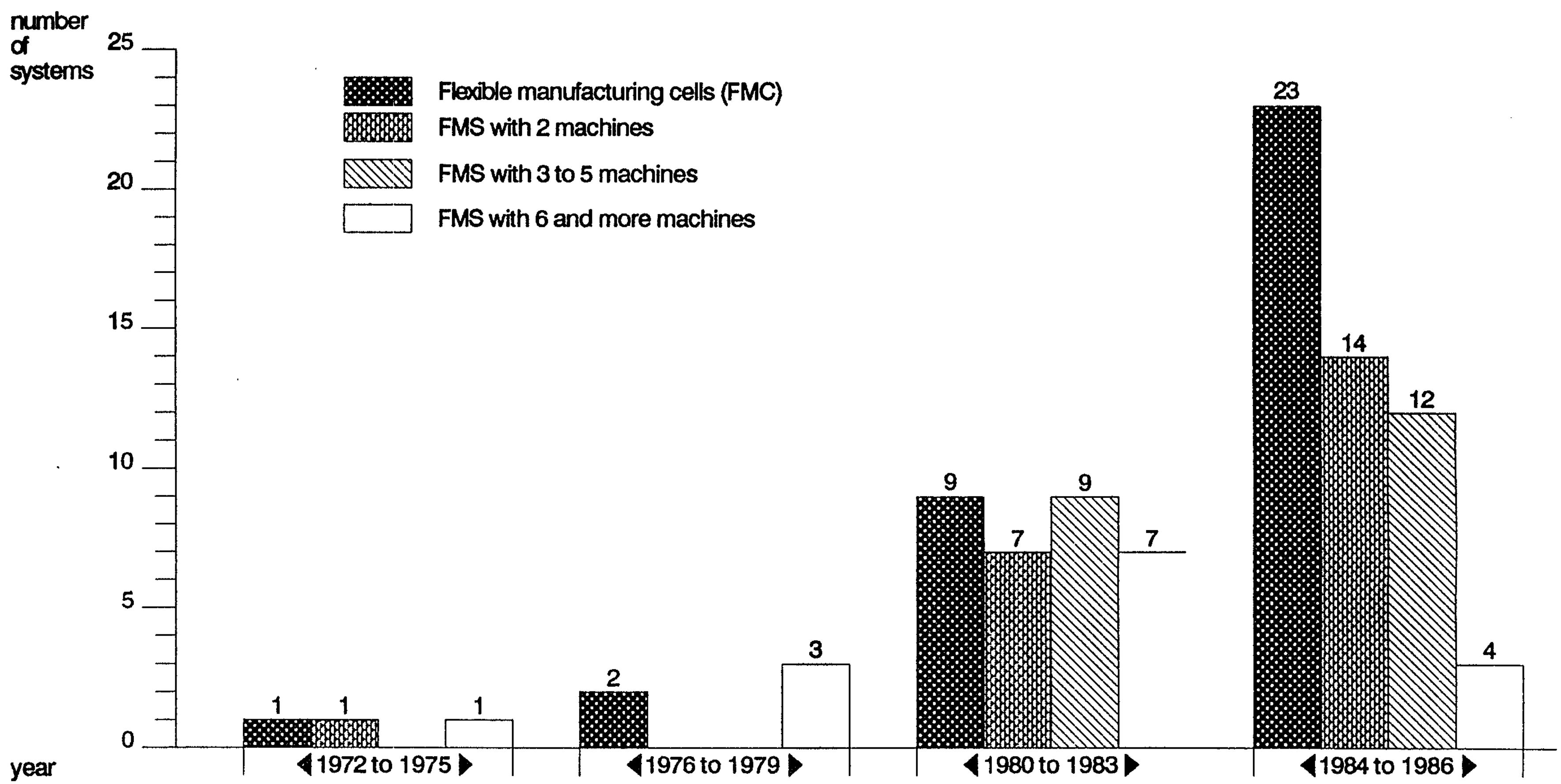

Figure 2.02	Application of Systems, According to System Size and Year Source: ISI/ISF-Survey (Fix-Sterz et al, 1987, p. 9)	ISF 1991

- On the other hand, the jobs in larger systems can be sub-divided to a greater extent than work at single NC or CNC machine tools.

Assuming that there are three basic alternatives of work organization as outlined in the introduction (I.2.), the Tayloristic, the polarized, and the skill-based types (Fig. 2.03), hardly one of the systems investigated in the ISI/ISF study could be categorized into the last group.[4] Even if there was a low degree of division of labour between system operators, most cases were characterized by relatively distinct dividing lines between the planning departments and system staff. For example, in none of the cases programming belonged to the regular duties of system operators, and planning and scheduling functions were assigned to the system staff in a few systems only.

Overall there was a slight preponderance of FMS with a high degree of division of labour between system operators (56% to 44%) In this respect, hardly any deviations in terms of system size could be stated; only two-machine systems were applied more frequently in set-ups with a high degree of division of labour (Fig. 2.04). This is probably due to the fact that these systems are the most standardized and advanced with regard to their central computer and their integration into higher computer levels.

This refers directly to the impact of the *degree of automation*. The higher the degree of automation in the material and information flow as well as in monitoring, the greater the ***potential for "decoupling"*** the workers from the manufacturing process. This potential for decoupling may again be used in two fundamentally different ways, however:

- to have the workers assume indirect functions which means a qualitatively better utilization of workers' skills during "idle" times;

- or to reduce the number of workers employed directly at the system.

Thus, the degree of automation and the automation technology are not determining factors for organization concepts and manning levels. But as a general characterization it can be pointed out that the scope for work organization normally is used to reduce direct shop-floor work and to assign planning functions to the staff in planning departments. One of the reasons for management's interests in reducing the number of shop-floor workers is the application of traditional justification procedures and cost-benefit analysis which calculate the profitability of an investment by the replacement of direct workers. In this context the calculation of a third "unmanned" shift is of special importance.

4 The skill-based type of work organization implies that in FMS (like in flexible production islands - cf. Engroff 1987) besides execution a considerable share of conceptual jobs is assigned to shop-floor workers; however, this does not implicate that they are exclusively responsible for these planning functions.

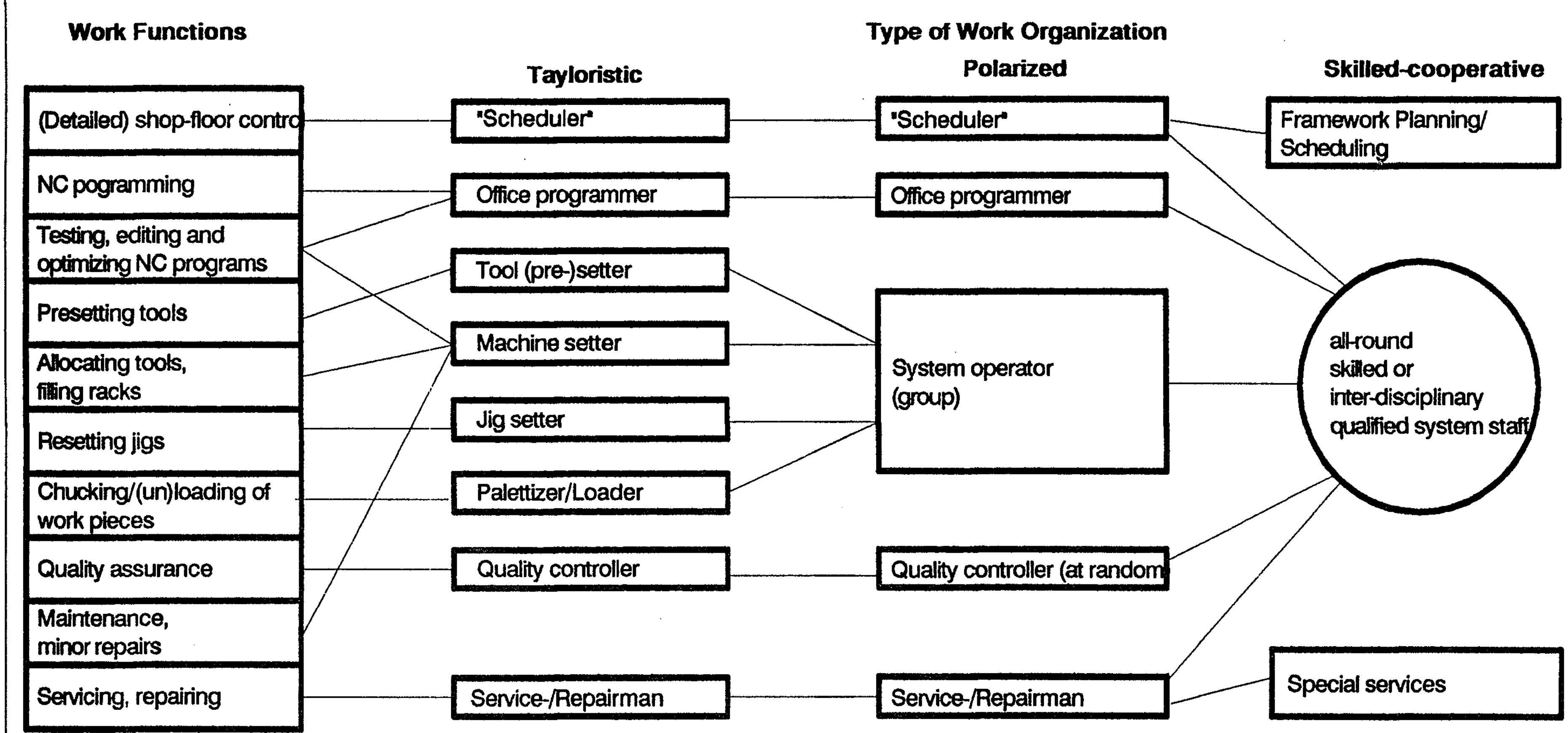

Figure 2.03

Basic Forms of Work Organization for Flexible Manufacturing Systems (FMS)

ISF 1991

System size	FMC		FMS with 2 machines		FMS with 3 to 5 machines		FMS with 6 and more machines		total	
Degree of division of labour on the shop floor	abso-lute	%	abso-lute	%	abso-lute	%	abso-lute	%	abso-lute	%
High	17	50	14	70	11	55	6	55	48	56
Low	17	50	6	30	9	45	5	45	37	44

Figure 2.04 **Division of Labour in Flexible Manufacturing Cells and Systems (FMC/FMS) According to System Size**

Source: ISI/ISF-Survey (Fix-Sterz et al. 1987, p. 20)

ISF 1991

However, this view of efficiency and profitability is not an imperative one (cf. Section 4).

The scope of work organization and the chances for skilled work have also to be seen in relation to the type of manufacturing system to be replaced by FMS. As mentioned above, FMS may be implemented to make former mass or large scale production more flexible without loosing in productivity, or - in other situations - to increase productivity in batch production without loosing much in flexibility.

- If mass production equipment is replaced, there are good chances to reduce the horizontal division of labour and to increase the share of skilled workers compared to the previous situation, even if work organization in its vertical dimension is kept stable.

- If stand-alone machine tools are replaced by an FMS, Tayloristic work organization means in any case a more selective and reduced utilization of the skills of experienced production workers.

- A polarized form of work organization may have positive and negative effects on the skill requirements for shop-floor workers at the same time: an increase because of the higher complexity and variety of technological components and functions; a reduction because new specialists for scheduling and programming are located "closer to the process" and acquire some of the knowledge and experience which skilled workers used to need before so they could cope with the planning specifications (and deficiencies) created "further away from the process".

The fact that a "creaming off" policy of the best-suited workers is virtually always employed for manning an FMS (Schultz-Wild 1991a) does not necessarily reflect higher skill requirements; it is first of all an indication of the significance of skills outside those directly required by the job (e.g. reliability) and of management's interest to secure the investment in this way as well.

On the other hand, there is reason to assume that the problems of running larger and more complex FMS - which also contribute to their slow diffusion - have to do with the strong degree of office-orientation and the lacking utilization of skilled work in the polarized and Tayloristic models as well (Gerwin 1982).[5] Several studies report that problems created by centralistic organization caused considerable changes in the system concepts during the implementation process (Roth, Königs 1988; Simonsmeier 1988).

5 This is indicated in an FMS case we studied. In-house software engineer were developing an explicitly deterministic control software for more than two years without convincing success. After numerous modifications they finally ended up with a graphic-interactive electronic control station open to shop-floor workers - and this some time before comparable control stations were available on the market.

3. System Components and Peripherals: Scope for Work Design

FMS subcomponents for machining, material and information flow take over and automate quite different functions, formerly performed by the work force. Consequently, they have a different influence on the organization and design of production work (Fig. 2.05). Nevertheless, an examination of the system components does not suffice in order to assess the organizational potential and the limitations of technologies. Peripherals must also be taken into consideration, in particular with regard to the vertical division of labour since planning and management instruments are more and more frequently becoming available on standard PCs, and these expand the organizational scope quite considerably. Software systems for planning, configuration, and cost-evaluation are also playing an increasingly important role as technical factors influencing decisions in favour of FMS and their design.

a) The Manufacturing System

The integration of different machining and processing methods offers a good opportunity to abandon the specialization of skilled work for certain machining methods and thus ensuring a flexible use of "interchangeable" workers. This suits the less specialized, young skilled workers trained according to the new training scheme for the industrial metal trades in the FRG (Schultz-Wild 1991a).

FMS for big-volume and complex parts offer a basically more favourable time structure for skilled labour since planning and scheduling tasks, such as NC programming, can be carried out continually in the longer periods between machining cycles. On the other hand, FMS designed for parts that need less machining time require frequent manual operations (i.e. chucking, loading) and hinder the performance of cognitive tasks. In such cases favourable conditions for skilled work would have to be intentionally created (e.g. by extending internal storage or by assigning different jobs to two or more workers, cf. Moldaschl, Weber 1986a).

b) The Material Flow System

Three features of the technical factors influencing the scope in work design can be identified in the material flow system; they all concern the degree of decoupling;

- First, the size of tool and work-piece storage. The larger the storage capacity, the easier it is to allot a continuous time structure for activities at the system, and the longer are the periods which can be used for planning and scheduling jobs.

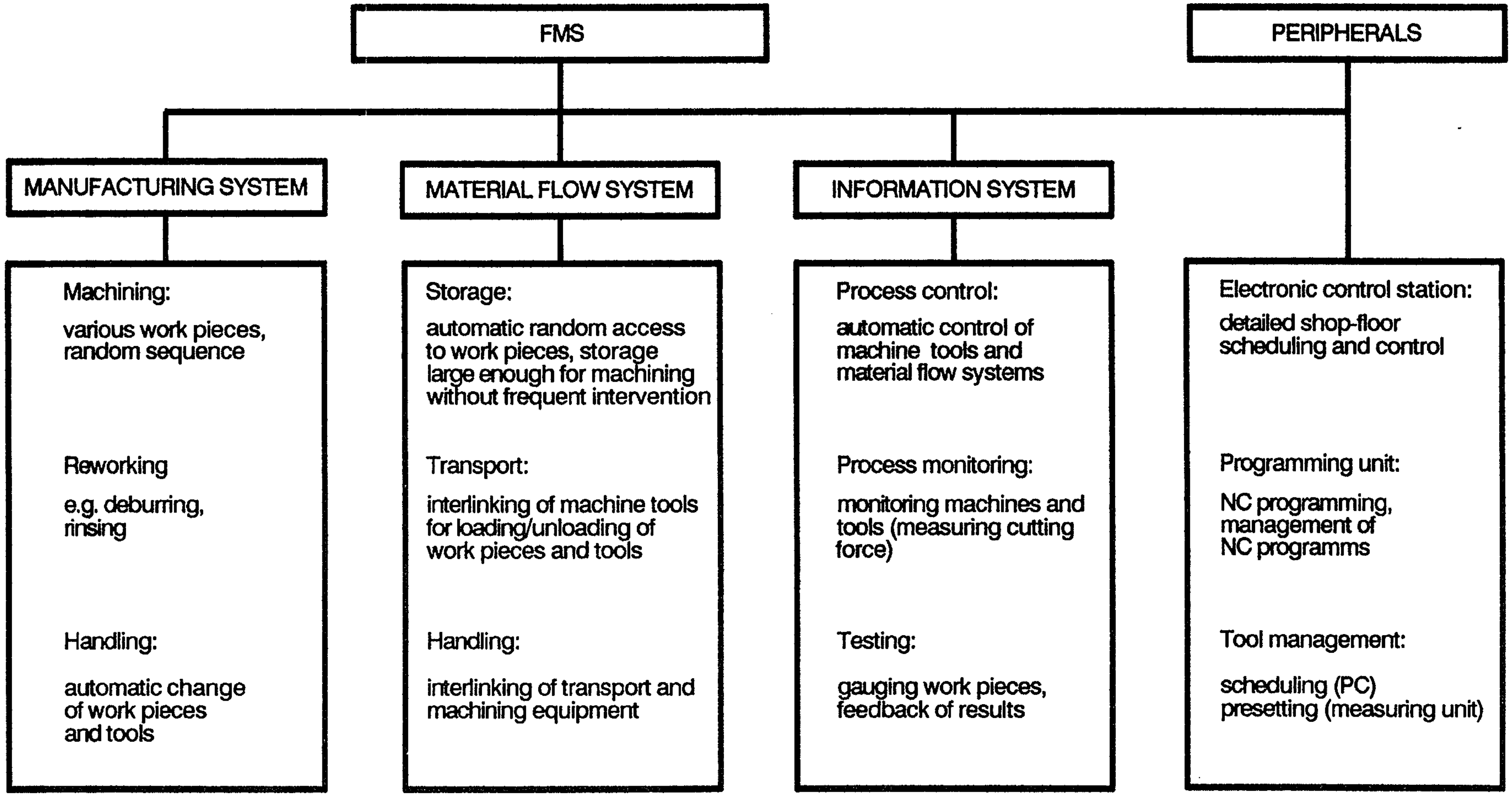

Figure 2.05	**Components and Peripherals of Flexible Manufacturing Systems (FMS)**	**ISF 1991**

- Second, the degree of automation of transport and handling of tools and work-pieces.

- Third, the reliability of the transport and handling systems; frequently and stochastically occurring troubles and brake-downs disrupt the time structure and obstruct the performance of planning tasks; examples for this can be found in the implementation phase of FMS and particularly in flexible assembly systems (Moldaschl 1990).

In the interest to establish a night shift with minimum staff, a high degree of decoupling and automation is pursued by manufacturers and users of FMS alike. Limitations result from the need of space for storage and the costs of tools (parallel availability) and handling systems.

On the other hand, the decoupling from machining cycles can also be used to reduce the number of operators per system or to assign two or more systems to one worker instead of enhancing the jobs by planning tasks. Decoupling can also be realized by non-technical means (i.e. by group work or the degree of manning, see Section 4).

c) The Information System

When the focus of automation efforts was on material flow until the first half of the 1980s, then later it clearly moved to internal information flow and its links to higher CIM levels.

According to the ISI/ISF study, in 1985 less than half (46%) of the systems surveyed in detail had a central control computer. At least among the systems presented since then in trade journals, there has not been a single system without such a centralized coordinating unit. The trend is obviously heading in the direction of interconnected control systems (Kief 1989).

While since 1985 many concepts have been presented for the internal computer architecture, only little progress could be made in the integration of FMS information systems into the superordinated information flow. As yet very few approaches have been worked out for linking FMS to PPC systems (Shah 1987; Schönheit, Wiegershaus, 1989; Eversheim et al. 1989). This constitutes a problem insofar as FMS without complete machining of parts have to be tightly interlinked with other areas of manufacturing, and the existing PPC systems can hardly cope with the resulting coordinating problems. While the best FMS control system cannot do anything to improve this, it can nevertheless be a more or less effective support for the permanently needed planning decisions at the system. Further support can be given by peripherals (see below).

The control system as the central interface for all system components has the following basic functions: detailed shop-floor scheduling, transport control, tool management, NC programme management, and production data acquisition. Not all the systems on the market provide all these functions.

With regard to order handling and scheduling, two strategic approaches can be distinguished, at least so far (see also Chapter III):

- First, control systems which provide algorithmic detailed shop-floor scheduling on the basis of internal allocation rules and optimization criteria, and organize necessary input via user guidance. Their objective is to convert centrally compiled job scheduling more or less automatically into a system-related procedure. This concept is frequently found in the first generation of standardized two-machine systems (Moldaschl, Weber 1986a). It contributes to a strong degree of division of labour at this type of FMS. Because of their lack of flexibility, these systems have not been able to gain acceptance on a broad scale.

- The second line includes graphic-interactive systems which are very similar to the electronic control stations to be analysed in Chapter III. Depending on the system, they offer a more or less large number of planning support functions. These systems are highly flexible and are suited for being employed by groups of skilled workers. The development towards the direction of even more flexible systems with new options and user-oriented dialogue interfaces is still in full progress.

With regard to the *DNC function* as well, a distinction must be made between internal system tasks and the function of external integration.

The internal system tasks (management and transfer of programs and corrected data) are to a certain extent an integral part of the operating system of the FMS and are significant for the work organization only insofar as they influence the degree of automation of the information flow and consequently the decoupling of workers from the internal processes.

The following tasks are the main ones performed externally with the DNC function: the link to an external programming system; the feedback of corrected programs to a centralized program management system; the transfer of machine and production data (running and idle times, number work-pieces, cutting speed, etc.). Here again, two typical concepts may be identified which differ in the extent to which they concentrate on office-oriented programming and a centralized compilation and processing of knowledge and experience, or whether they are open for decentralized forms of work organization (see Chapter IV).

d) Machine Control

Although these days every modern CNC control has the possibility to enter data and edit programmes manually, very clear differences may be identified in the programming concepts.

Computer-science-oriented concepts operate on the one hand with a higher "problem-oriented" programming language (mainly of the APT language family) and aim at automatic programming (automatic calculation of geometry and technological parameters) for more complex parts. Systems on this basis require longer training periods and are usually not employed on the shop-floor. On the other hand, programming may be carried out semi-automatically or manually in a language close to the machine (DIN programming). Manual input in "low-level" language is very time-consuming and therefore used infrequently, mainly for simple parts.

Shop-floor-oriented concepts can be categorized into three approaches:

(1) The play-back method in which skilled workers create the programme through a concrete machining process in a quasi-analogue manner and without any programming in advance. Despite its advantages - especially for experienced older skilled workers - this approach has hardly been used as yet (Hirsch-Kreinsen 1989; Dunkhorst 1989).

(2) Systems with a dialogue interface based on clear text.

(3) Graphic-interactive programming systems which use descriptive symbols and graphic elements instead of a programming language. Using these, the work-piece geometry can be put together successively in some sort of a dialogue by means of soft keys. As a result programming tends to be simplified and reduced to entering parameters.[6]

The basic approach of these concepts is to simplify and structure the programming in such a way that a skilled worker even without in-depth knowledge of programming is able to programme the machines on the basis of his usual way of thinking and manner of working. This enables operators to become familiar with the systems quickly. The high degree of programming support guarantees high productivity in programming directly at the machine which means a high efficiency in learning and working. As a result, skilled workers are not only able to assume programming tasks but are encouraged to do so as well.

However, DIN and ISO-oriented controls are increasingly being equipped with appropriate programming tools as well. Even though producing a programme

6 Graphic-dynamic simulation makes the immediate visual control of the programming results possible, and backs up with automated plausibility controls and collision monitoring ("Shop-floor-oriented Programming Procedures - SOP", cf. Hekeler 1988; Häuser 1989).

may still remain more abstract, under certain circumstances programming complex parts can be more flexible. With a progressive, computer-science-oriented solution, the skilled worker is not submitted to a computer-guided dialogue. However, this would demand a greater amount of training and relatively higher expenditures for programming of parts that are not very complex (Weber 1988; Böhle, Rose 1990).

Thus, between the purely office-oriented and the explicitly shop-floor-oriented programming systems, a range of control systems is establishing itself which make computer-aided skilled work a feasible alternative.

e) Peripherals

Decreasing prices and constant improvements in efficiency on standard PCs are increasing the availability of every imaginable computerized aid to planning, scheduling, coordinating, and control of production processes at every level of a company. Technical limitations to reintegrating conceptual work on the shop-floor, which result from the installation of FMS components inadequate for this purpose, may almost always be compensated today by supplementary equipment of FMS peripherals.

If, for example, machine controls or DNC computers are not suitable for shop-floor programming (e.g. because programming parallel to machining is not possible), programming units on a PC basis optimally adapted to the parts-spectrum may be used close to the system. Ideal for this type of application are systems which were developed in the "SOP"[7] project; they not only offer a uniform dialogue for all manufacturing methods but also a uniform procedure for office and shop-floor.

Inadequate user support with detailed production planning (job sequencing, machine scheduling, etc.) by the FMS control station and the integration into the whole production process do not longer constitute an argument against operating the system by staff itself since highly convenient and shop-floor-oriented electronic control stations are available, and their investment costs are negligible compared to those of the entire FMS.

The same applies to the functions of tool presetting and tool management. Optical and opto-electronic presetting equipment can be installed directly at the FMS, or, in the case of insufficient utilization, in the centre of a larger shop-floor area. Easy-to-handle tool management computers are well able to support FMS-external tool management by a group of skilled workers.

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7 "SOP" = "Shop-floor-oriented Programming Procedures" (in German: WOP) was the common heading of a government sponsored project under which a number of companies and engineering institutes cooperated (cf. Ammon 1988; Liese 1989).

4. "Decoupling" People by Technical Means is Not Sufficient

Even though in the individual case there might well be technical limitations to integrating jobs and forming skilled work groups on the shop-floor level, there is nevertheless a wide range of FMS components and peripherals available. Further flexibility and shop-floor-oriented systems appear to be current trends as well.

The possibility of using the existing scope of organizational design to promote computer-aided skilled production work has proven to be centrally dependent on non-technical parameters of *personnel requirements policy*. Whether the "decoupling" from the production and work processes may also become effective for system operators, and whether the higher degree of automation does in fact grant more autonomy to operators as against the system pace, will finally be determined by the number of workers employed at the system (Moldaschl 1989).

A small relatively too small number of workers operating the system means that the work of the system staff has to be reduced to palettizing or system (un)loading and setting of jigs and fixtures. Operating the system then usually means nothing more than some sort of multi-machine operation. This form of employment is encountered frequently because it corresponds to the attitude towards costs in the classic rationalization approach which utilizes automation-related time-saving to minimize shop-floor labour (e.g. J. Martin 1988).

Even if setting-up and loading do not account for all the working time, the time structure of necessary job performance often prevents the execution of other and additional jobs. The remaining idle time between loading operations fragmented by other instances requiring intervention, caused in particular by stochastic disturbances. These are mainly trivial disruptions lasting up to ten minutes (Wiendahl, Springer, 1986, p. 98). Due to these factors sufficient time spans and structures for scheduling, programming, preventing breakdowns, and quality-related activities cannot be created by technical means alone (Moldaschl, Weber 1986a, b; Plath et al. 1986); work organization and work design must create the necessary preconditions. The assignment of planning task to the system personnel is at the same time the prerequisite for scheduling the work procedures in such a way that sufficient intervention-free time is created, e.g. for programming.

With regard to the use of labour, Roth (1988) could prove on the basis of an FMS design example applied in the automotive industry that a larger system staff not only makes skilled group work possible in the first place but that this is also profitable particularly due to the higher degree of FMS utilization achieved and due to lower costs outside the system.

Manpower requirements policy creates, at second glance, an enormous potential for organizational alternatives which are well able to *compensate existing technical limitations*.

In this context a further category of computer-aided tools for the implementation and utilization of FMS in companies should be mentioned: planning, configuration, and cost analysis systems for investment decisions regarding FMS, which in the meantime are widely available and more and more are appearing on the market (Eversheim, Fromm 1986; Mamalis et al. 1987; Eversheim, Schönheit 1989). These planning systems are gaining influence on the technical and organizational design of FMS; however, so far they provide no means for judgements about the significance and efficiency of various forms of work organization, and the number and skills of staff. In this respect there is still a large gap in research and development.

This methodological deficit generally relates to the comparison of basic alternatives concerning technology and organization. Thus, bearing the scope for different design alternatives of FMS in mind, there are many reasons for assuming that the less automation-oriented concepts of *flexible production islands* are better suited both to skilled and cooperative group work as well as to company interests in low-investment and thus low-risk increasing productivity and flexibility (Brödner 1985; Engroff 1987). To prove this, an adequate forecast of the cost-effectiveness would be desirable for companies on the brink of innovation. It should be based on an extended set of cost-relevant parameters and allow for considering important long-term, indirect and qualitative effects of organizational alternatives (ability for short through-put times and high reliability of delivery dates, costs of indirect labour and labour turnover, motivation of workers).

In the technical and organizational planning of FMS or production islands, manpower policy based on preserving or enhancing the employment of skilled labour can be backed up by *prospective work analysis procedures*. These enable the evaluation and possible modification of alternatives beforehand in accordance with criteria - like skills and work-load - before facts and constraints are created that are difficult to correct or reverse. Practical experience with methods of prospective work analysis and work design are already available (e.g. Moldaschl, Weber 1986a; Plath et al. 1986; Volpert et al. 1989).

III. Alternatives in Production Planning and Control[8]

New means of production planning and control have been appearing on the market for some years now. One category of these are shop-floor scheduling systems or manufacturing control modules oriented towards the structures of comprehensive PPC systems. The other type are the "electronic control stations" (elektronischer Leitstand) with a user-friendly graphic display based on the classic planning board (Ganttchart), interactive scheduling concepts and their own data-base on PC or workstation.

In this chapter, first the differences between the two types of manufacturing control systems will be explained. Then, the technical and organizational forms of employing the respective technology lines will be analyzed. The chapter will conclude with a few assumptions on the further development of production planning and control.

1. Development Lines of Production Control

At the beginning of the 1990s, more than one-third of all the companies in the capital goods industry of West Germany are using computer systems for production planning and control (PPC). In the mechanical engineering and electrical engineering industries this figure is 40%. Similar to other types of computer technology, PPC systems are employed more frequently by large companies than by smaller ones. Correspondingly, 80% to over 90% of companies with 500 or more employees use PPC systems (see Schultz-Wild et al. 1989, p. 35 ff; Schultz-Wild 1991b).

a) Deficiencies of PPC Systems

Unlike materials and capacity requirement planning, manufacturing control and in particular detailed shop-floor scheduling was a weak point of PPC systems for a long time (see Scheer 1988). This applies in particular to the production of small and medium-size batches in mechanical engineering with its high degree of unpredictable and "unscheduled" disruptions, where short-term rescheduling is often necessary, and where generally a high level of process complexity exists. Even into the 1980s, most of the PPC shop-floor scheduling modules on the market had two main problems:

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8 The following arguments are based on several sources: 1) Discussions with experts in research institutes and with producers of manufacturing control systems. 2) Some 25 case studies (conducted between 1987 and 1990) in companies of the metal industry with long experience in the use of PPC systems. 3) A survey conducted in the summer/autumn of 1989 with the 11 producers/vendors of electronic control stations known at the time. 4) An expert report of the IWI Saarbrücken on the subject of the technical features of these systems on the market and their suitability for semi-autonomous work groups and production islands (Hars, Scheer 1990). A detailed account of the research findings can be found in Schultz-Wild et al. 1989; Köhler 1990.

- First, the immense amount of data could only be processed in weekly (or weekend) batch runs due to the restrictions imposed by the hard- and software. The extensive lists - not rarely files of substantial magnitude - of detailed job sequences often became outdated within a few hours.

- Second, the highly automatic scheduling processes focused on capacity balancing and sequencing using algorithms which did not allow for ad-hoc alterations. Frequent changes in capacity, load, and priorities could thus not be taken into consideration.

The performance of these types of PPC systems and modules was by far overestimated. Their deterministic planning methods and detailed schedules were employed directly for job sequencing. At least in the production of small and medium-sized batches this caused a lot of troubles (Pabst 1985; Manske 1987, 1990; Schultz-Wild et al. 1989). These systems were often "defused" only after long and harrowing mishaps: The detailed scheduling modules sometimes remained unused, sometimes the machine utilization plan only served as a rough orientation at the beginning of the week; in extreme cases, as the head of one "PPC-injured" company reported, "they pulled out the plug".

Improved performance and lower prices for hardware, and the further or new development of software components have led to an upsurge in innovations in PPC systems since the early 1980s. One result of this development is the differentiation of the system architecture into three levels (Fig. 3.01):

- production planning and control (from sales through to job release),

- manufacturing control / scheduling (from job release through to detailed machine tool utilization plans), and

- manufacturing control / execution (from real-time scheduling, job sequencing and process control through to production data acquisition (PDA) and monitoring).

Spectacular changes can be observed on all three levels.

In production control two lines of development can be identified. These are electronic control stations on the one hand and central shop-floor scheduling systems or modules on the other (see Friedrichs, Gromotka 1989).

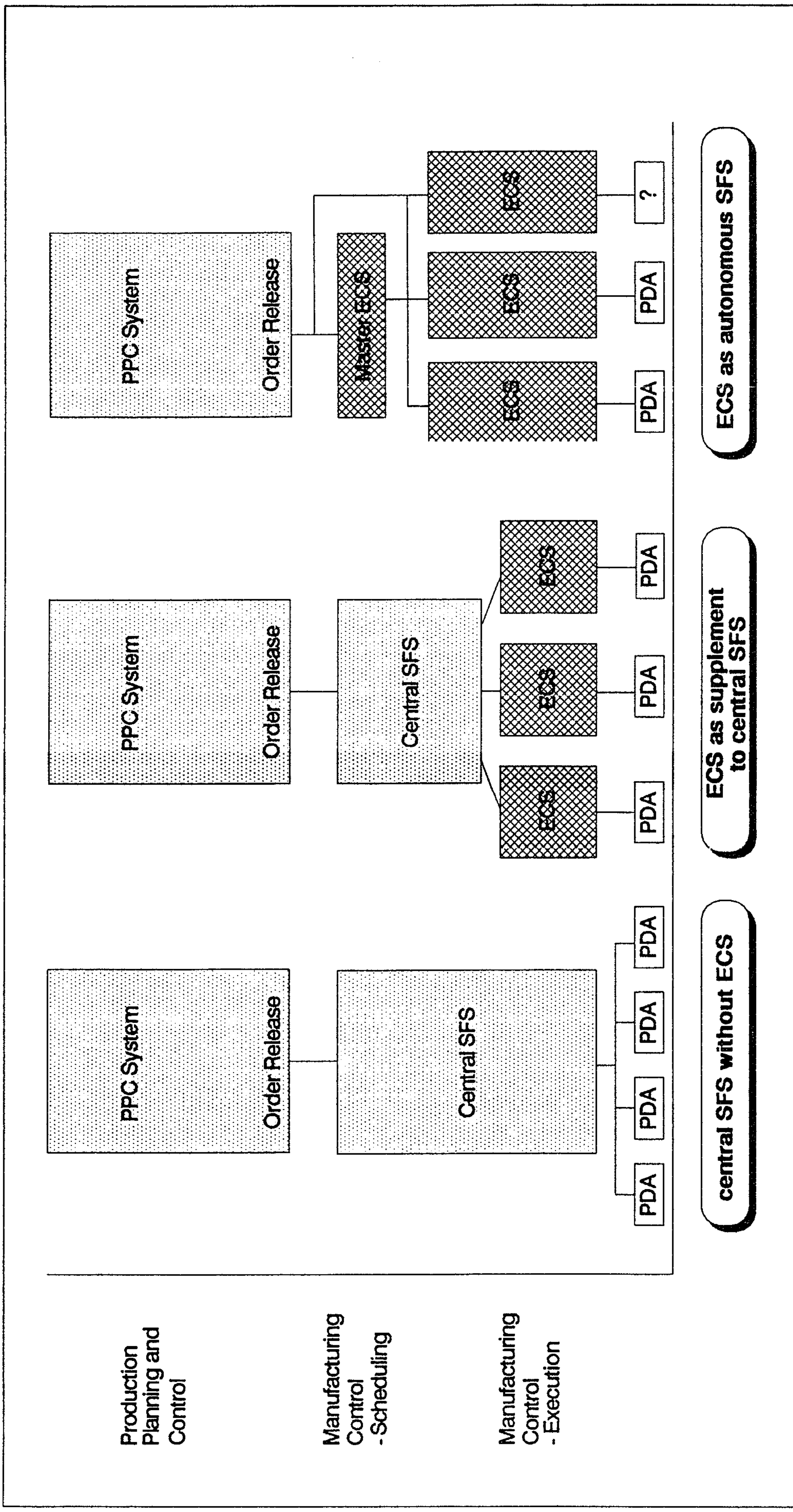


Figure 3.01 | Technical Concepts of Shop-floor Scheduling Systems (SFS) and the Application of Electronic Control Stations (ECS) | ISF 1991

b) Electronic Control Stations

Electronic control stations have the following distinct features (Hars, Scheer 1990; Jackson, Browne 1989):

- They run on autonomous small computers (PC-ATs, workstations) with their own data-base and with an interface to PPC systems.

- In their functionality and user interface they concentrate on the core function of detailed scheduling. The functional range is built up successively, however.

- The scheduling procedure is characterized by an heuristic concept. Emphasis is not placed on algorithms but rather on the dialogue with the user.

- The graphic display is modelled after the Ganttchart, representing workplaces on one axis and a time-scale on the other. Using a mouse, the operator can plan and re-plan orders interactively and carry out a wide range of other operations (e.g. changes in display details, graphic analyses).

Control stations are designed for the needs of small and medium-size batch production. The functional range and data-bases are built up successively. Automatic scheduling using different heuristics can also be provided, but the emphasis remains on the dialogue. The user interface is easy to handle and is readily accessible by "part-time schedulers" such as foremen, group leaders, and production workers.

Control stations are technically and economically compatible with various organizational forms of production control. Due to the features mentioned above, they are suitable both for centralized forms of production control (by specialized personnel scheduling large units) and decentralized forms of production control (by foremen, group leaders, or productions workers in small units). Consequently, they may be described as an *open* technology line.

c) Central Shop-floor Scheduling Systems

Central shop-floor scheduling systems, mostly sold as modules of comprehensive PPC systems, differ from electronic control stations principally in the following features:

- They run on medium-sized or large computers (e.g. DEC-VAX and upwards).

- Their functional range usually encompasses all areas of manufacturing control from detailed scheduling, material, and manpower management to PDA and DNC functions.

- The level of automation of scheduling and control functions is high. Thus, fully or semi-automatic routines (algorithms) are offered in all functional areas. They range from the automatic compilation of lists to search runs with several parameters and automatic scheduling of detailed job sequences on individual machines.

- The user interface is oriented towards full-time system operators and the display of large production units. The emphasis has not been on developing object-oriented forms of display and graphic-interactive scheduling.

Due to the above-mentioned features, this line of technology is especially suitable for organizational forms of *centralized manufacturing control* (by specialized personnel controlling large units) but not for forms of decentralized manufacturing control (by foremen, group leaders or production workers). Equipping a large area with small units of interactive terminals would normally be more than the capacity of the hardware could handle, and would result in response times unacceptable for real-time control. Parallel scheduling of many small units is frequently not provided for in the software structure and would require large-scale, time-consuming, and expensive adaptations. The cost of the hard- and software (frequently in excess of DM 200 000) is an argument against seeking to solve such problems by purchasing a larger number of these systems.

In addition to restrictions imposed by the hard- and software, the *user interface* is a considerable obstacle to a utilization in decentral set-ups. Because of the time needed to master the functional complexity and the user interface, it would seem more logical to have full-time system operators, however, scheduling the work for a foreman's unit or a work group does not make up for a full-time job. On- and off-the-job training take time; acquired knowledge is quickly forgotten if the operator works only sporadically with the system (as within a group). The gap between the knowledge and experience of first line management and production workers and the abstract operational logic of the systems is too big.

d) Technical Concepts of Production Control

In line with the distribution of data and functions on the various PPC levels, three technical concepts of production control can be differentiated today (Fig. 3.01):

- In the first concept, a centralized system for manufacturing control is dominating (either as a PPC module or as an independent system with its own data-base). The centrally calculated schedules extend to the job sequences of individual machines or workplaces.

- In the second concept, electronic control stations (ECS) are employed to supplement a central system for shop-floor control or module. Since the modern central systems have a high scheduling frequency (mostly daily) and a high accuracy, the remaining scope for decisions at the control station is relatively small unless a larger scope is provided for systematically in sub-areas of production (e.g. production islands).

- In the third concept, electronic control stations are employed as independent manufacturing control systems. Some manufacturers of such systems are working on a master control station to function as a coordination system below the production planning level (see Hars, Scheer 1990).

These three technical concepts of manufacturing control can complement each other: Centralized systems are used in large companies/company departments producing medium-sized or large batches; electronic control stations are more likely to be found in small companies/company departments with highly complex production processes. In the engineering sciences, however, lobbies can be found which consider centralized systems of shop-floor scheduling to be an alternative to electronic control stations and which favour one line or the other (Friedrichs, Gromotka 1989; Herterich, Zell 1989; Jackson, Browne 1989).

2. The Technical and Organizational Integration of Central Shop-floor Control Systems[9]

In accordance with the first concept, central manufacturing control systems are generally employed for detailed job sequencing right down to individual machines. Improved and distributed hardware, further modularization of the software (decentralized control circuits), improved dialogue techniques, and the application of PDA allow extensive automation of these functions.

This normally has decisive consequences on how production control is organized. The high degree of automation of scheduling functions leaves relatively little scope for human intervention. The remaining scheduling tasks can be centralized. It is common to find the organizational form of centralized manufacturing control in which either a central control station determines the mandatory detailed scheduling for large production areas (encompassing several formen's units), or the production control department is responsible for the entire factory. On the basis of detailed machine tool utilization plans, this central authority issues mandatory control commands to the shop-floor and monitors the

9 With regard to this and also as background to the following comments, see the comprehensive sociological analyses of Manske on production control in mechanical engineering (1987, 1990). See Strack 1986 in particular, and Schultz-Wild et al. 1989, p. 171 ff. for analyses on organizational forms of production control.

progress of work on the job. First line management on the shop-floor and production workers are no longer called on to perform organizational tasks; therefore they will loose their ability to keep the manufacturing process flexible.

Organizational forms of this type are *not necessarily* the consequence of the technical structures of central manufacturing control systems. Some latitude in decision-making may be conceded to foremen and machine operators by laying down less detailed schedules.

However, a decision once made for employing a central shop-floor scheduling system seems to presuppose centralized forms of work organization as well. This is without a doubt the general mainstream trend in applying modern PPC systems. There are many economical, social, and political factors supporting the type of Tayloristic concepts in production control (see Köhler, Schmierl 1991). It should be emphasized here - in the context of technical constraints - that due to their hard- and software limitations, central systems are not suitable for supporting decentral decision-making. With the increasing economic importance of short through-put times and high reliability of delivery dates, it makes little sense for many companies - especially once they reach a certain size - to curtail the scheduling accuracy of these systems consciously and do without computerized tools supporting their manufacturing control.

Centralized systems for manufacturing control which determine job sequences down to the individual machine tool are hardly reconcilable with forms of "skilled and cooperative production work" with decentral scope for decision-making (see I.2. above). They are suitable in particular for forms of computer-aided Neo-Taylorism or polarized production work.

Only the supplementation or substitution of central shop-floor scheduling systems by control stations opens up a degree of latitude for organizational design. For this reason, the following remarks focus on the application of this relatively new, and still little utilized technology.

3. Technical and Organizational Integration of Electronic Control Stations

A survey of 11 producers of electronic control stations covering about 320 systems[10] in West Germany shows that the main area of application is typically in the medium and large-scale mechanical engineering companies with customized and small-batch production organized in job-shops. About two-thirds of the sur-

10 In the summer of 1989, according to the 11 surveyed producers and vendors of electronic control stations in the Federal Republic of Germany, there were some 190 systems in use. A further 130 installations were planned to be in operation by the end of 1989. For these, manuals already provided in concrete form the contours of how they were to be used. This total of some 320 control stations is the basis of the following analysis.

veyed control stations fall into this categories (Fig. 3.02). In 14% of all cases, control stations were employed in production islands.

a) Technical Integration

Almost all control stations are linked to PPC systems. The scheduling frequency of PPC systems in batch runs (Fig. 3.03) ranges from one day (45%), to two to five days (51%), to six and more days (4%). The control stations normally take over preplanned and released orders corresponding to these frequencies. The core functions of detailed job sequencing and control are fully utilized. In about 60% of the control stations in use, the complete scheduling of all the preplanned and released orders on hand is consequently carried out each shift or daily, and in about 40% of all cases this is even done several times per shift (Köhler 1990).

While in the meantime almost all producers of electronic control stations offer interfaces to various production-related sub-systems, in practice they have not been employed very much so far (Fig. 3.04). PDA is an exception. In about half the control stations surveyed, there is a direct data link to a PDA system. In the remaining half, data on the progress of jobs is collected manually by means of forms or oral reports.

Control stations have proven their worth as effective and up-to-date information, scheduling, and control systems. Obviously they achieve a degree of accuracy and precision far greater than that of the older PPC systems with their weekly batch runs, but also of the modern systems with central scheduling modules and daily batch runs.

b) Organizational Integration

Almost two-thirds of the control stations installed today are used according to organizational structures of *centralized* manufacturing control (Fig. 3.05): They are operated by specialized personnel responsible for several foremen's units and job-shops. Since the scheduling accuracy of control stations is generally very high, the foreman loses many of his control duties in such cases.

All together, only slightly more than one-third of all the control stations surveyed operate in organizational settings of *decentralized* manufacturing control:

- 28% of all control stations are used as decision-making support for the foreman; the number of controlled work places is less than 50 in half of these cases, and between 50 and 100 in the other half.

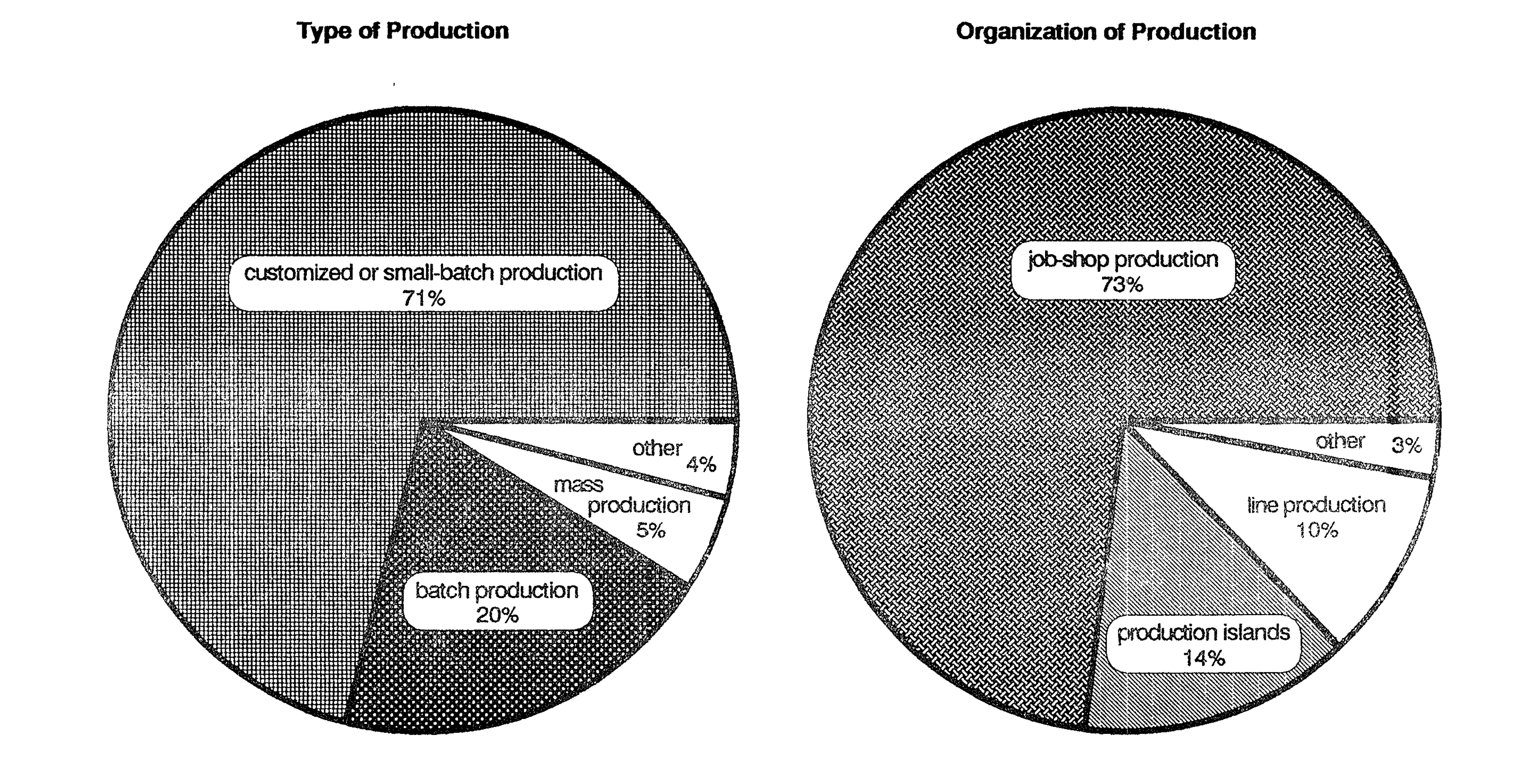


Figure 3.02	Electronic Control Stations (ECS) - Areas of Application (320 Cases)	ISF 1991

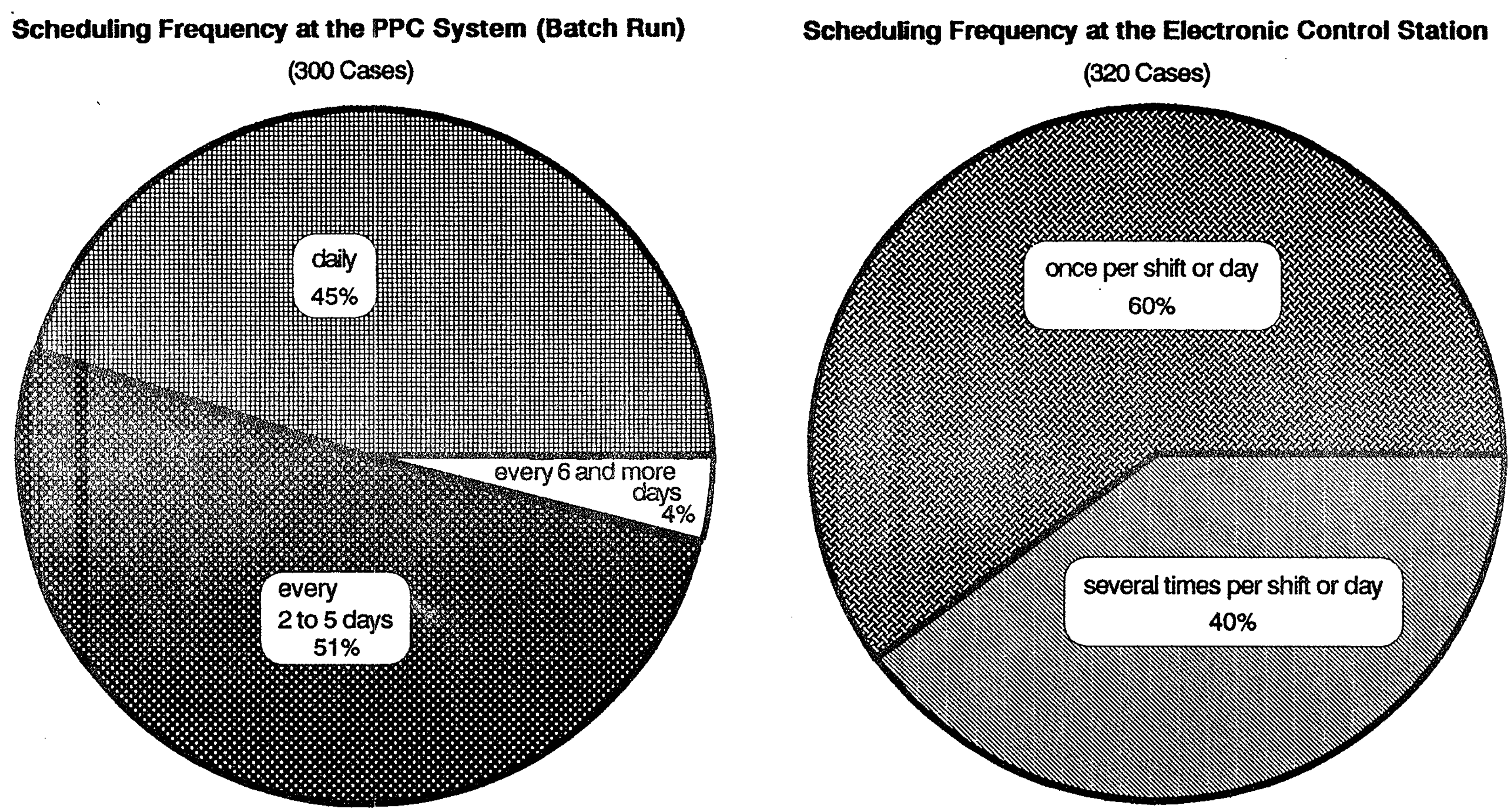


Figure 3.03	**Scheduling Frequency at the PPC System and the Electronic Control Station**	**ISF 1991**

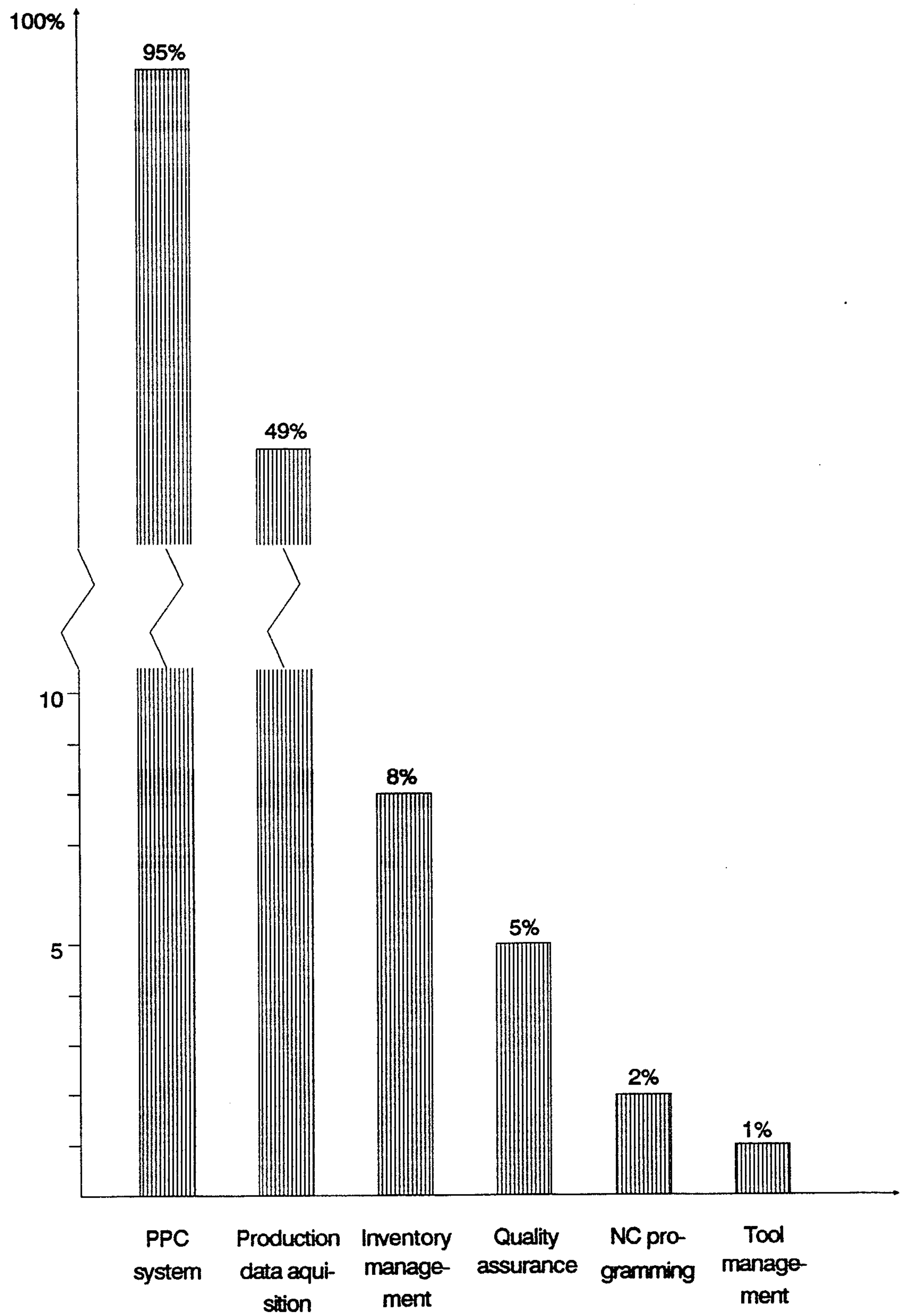
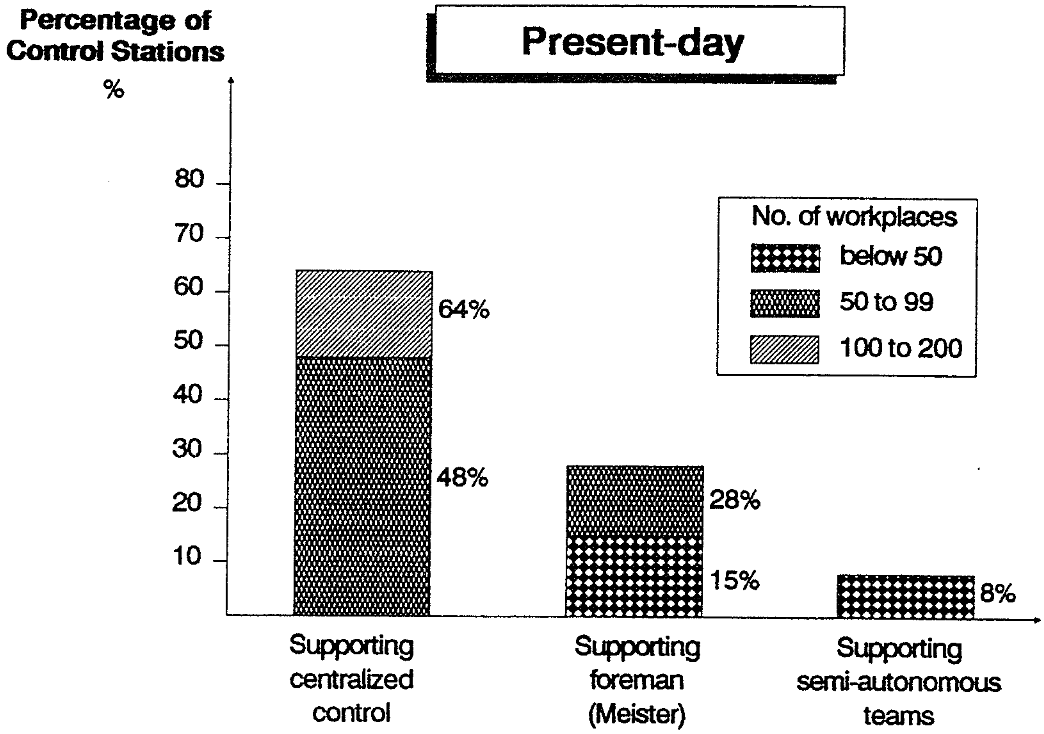


Figure 3.04	Computer Integration of Electronic Control Stations (ECS) (320 Cases)	ISF 1991



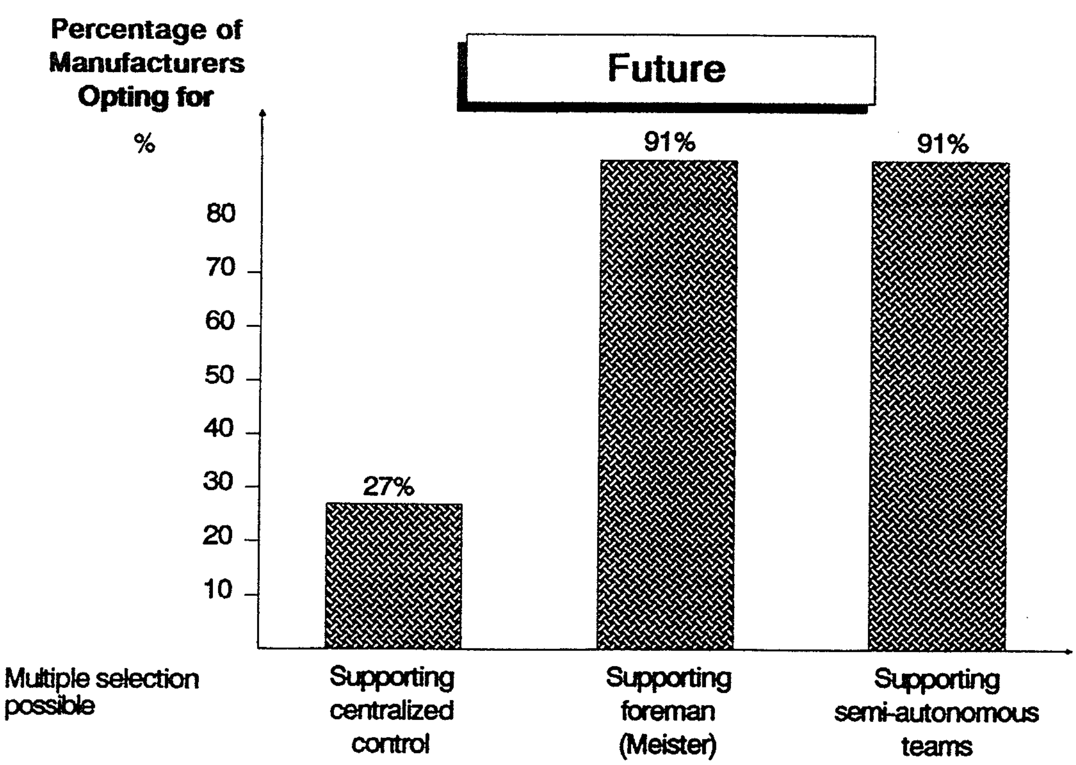


Figure 3.05	The Organizational Integration of Electronic Control Stations (ECS)	ISF 1991

- Only 8% of all control stations control smaller units. The system is then used in the context of group work (e.g. in a production island for the purpose of creating detailed machine tool utilization plans) and is normally operated by the group leader.

The organizational forms of *centralized* manufacturing control are still prevalent in the utilization of control stations. The producers predict a trend towards decentralization, however. Among the eleven companies surveyed, eight, including the leading two producers in terms of sales, expect forms of decentralized manufacturing control (by a foreman or a semi-autonomous group) to be the only ones which will prevail when employing control stations in the future. Two producers advocate both centralized and decentralized development paths. Only one producer views the centrally employed control station as the ideal solution.

4. The Participation of Production Workers in Manufacturing Control

The organizational integration of electronic control stations does not remain without repercussions for the division of labour between production workers, foremen, and specialized control personnel regarding detailed scheduling. Production workers have always been and still are integrated in shop-floor scheduling in many areas of mechanical engineering as they are involved in the selection of the "job bundle" assigned to them and decide on the sequence within the bundle (see Manske 1987, 1990). As a result, decentral logics become important (the interests of wage stabilization in piece-work systems, optimization of set-up times, stress reduction, job variation, etc., may be mentioned here); they can sometimes counteract central logics, but sometimes support them as well.

This decision-making latitude of production workers will undoubtedly be curtailed by the modern manufacturing control systems which operate with increasingly accurate and detailed schedules. The application of control stations reinforces this trend by simplifying the job sequencing for individual machines. Thus, regardless of the organizational form of manufacturing control, the practice of allocating individual jobs instead of job bundles now seems to be finding increasing acceptance.

One indicator for this development is the extensive utilization of the scheduling and control functions of electronic control stations. At almost all the systems in use today, released orders are scheduled in detail including starting and finishing times of individual operations. In almost all cases these schedules are updated continuously or at least several times per shift and day. As a result, any rescheduling, prompted by urgent orders, breakdowns, etc., is handled by the control stations. The high degree of PDA utilization and monitoring of work in progress are pointing in the same direction.

However, depending on the organizational structure of manufacturing control, this trend has different consequences for workers. They are integrated in the manufacturing control process in the highest degree wherever - as in the minority of some 8% of the cases - control stations function as a decision-making support for semi-autonomous groups, as in production islands for example. Even when the job sequencing is determined by a group leader, the group members have a great deal of influence. In a group of 8 to 15 production workers, it is possible to incorporate the knowledge and experience of the individuals into the planning by means of a favourable allocation of jobs to machines and workers (e.g. taking into account dependencies of set-up times) and in line with the interests and preferences of the group members.

The larger the area of responsibility, the more difficult it is to involve production workers in the scheduling and control process. A foreman in a mechanical manufacturing job-shop may have to supervise between 30 and 100 workers depending on the complexity of the process and the company organization. In the range of 50 machines or more, the influence of the workers is likely to be restricted to subsequent minor revisions of the job sequencies. Only in smaller units closer forms of cooperation are feasible.

Production workers are likely to have the least influence when control stations are used within organizational structures of centralized manufacturing control. This is the situation in just about two-thirds of the systems where the scheduling of up to 200 machine tools is carried out. Even partial integration of production workers in the scheduling process would overtax the information processing capacity of the control operators, and for that reason will usually remain an exception (unless workers have been given some latitude through the allocation of "job bundles").

5. Development Trends

To summarize, two concepts of the technical and organizational integration of control stations can be identified today:

- In the first concept control stations function as supplements to central shop-floor scheduling systems. They tend to be but stopgaps for centralized planning and scheduling.

- In the other concept, the control stations are operated technically with a large degree of scheduling latitude as independent systems below the production planning level; organizationally, they support decentral units.

In the first concept, control stations are simply a means of transferring and adapting central scheduling to the shop-floor. When they are used in a decentralized manner (as an aid for the foreman or semi-autonomous groups), little scope for decision-making is left; this type of utilization will possibly become obsolete in the further development of centralized manufacturing control.

In the alternative concept (see Gottschalch 1989; Jackson, Browne 1989), control stations are given a high degree of autonomy in scheduling functions (with planning terms of up to five days or even several weeks). Sometimes this autonomy is extended to process engineering and routing functions. The coordination between decentral units (e.g. production islands) and the production planning level is taken care of by either central shop-floor control systems or a master electronic control station. From an organizational viewpoint, the control station is allocated either to a foreman or to a semi-autonomous group. The central monitoring of work in progress is characterized by the motto "as much as necessary and as little as possible".

Both concepts and development trends signify ranges of the application of electronic control stations which vary depending on the size of the company, the type of production, the organization of manufacturing, and the company philosophy. A glance at the modern centralistic concepts can easily convey the impression that the mistakes of earlier PPC developments are being repeated. The scheduling and control potential is overestimated, valuable and irreplaceable skills of workers and supervisors on the shop-floor remain unutilized or are even lost. While the modern systems have pushed forward the boundaries of scheduling by yet another milestone, they have by no means solved the fundamental problem of complexity in manufacturing control in the area of batch production.

The application of modern PPC systems and strategies of production segmentation were able to bring about a considerable reduction (sometimes up to 50%) in through-put time in many companies. In mechanical engineering with job-shop production, however, the main application area of control stations, these strategies have specific limitations: below a certain buffer size, capacity utilization declines.[11] If it is not possible to go back to alternative jobs when problems with the scheduled jobs arise (missing jigs, tools, NC programs, etc.), the machines will stand still. As much as ever, long idle periods for semi-finished products have to be tolerated if the more and more capital-intensive facilities are to achieve high operating times. If the average through-put times of parts requiring ten operations in mechanical manufacturing was three months in many enterprises prior to their modernization (e.g. production segmentation and new PPC systems), then six to eight weeks is considered as a good result. With the

11 JIT strategies also have their limitations in mass production with the result that buffers, decentral scope for action, and possibly control stations make sense. See Moldaschl 1990.

exception of urgent orders, it is hardly possible to improve on a few days of idle time per operation when small parts are manufactured (Wiendahl 1987, p. 288 f.).

If just-in-time remains an illusion in batch production, then there will be still much scope for optimizing the allocation of jobs, manpower, and machines by the foremen and by production workers to reduce set-up times, to improve quality and through-put speed, to meet deadlines, and to increase work satisfaction and motivation. Much of the information necessary for decentral optimization processes cannot be easily computerized; for example set-up times which depend on the respective previous job provided a low repetition rate of parts (set-up time matrix), for example. This also applies for production workers' control knowledge based on experience and sometimes mental pictures which cannot be communicated easily. What cannot be computerized at all are unforeseen occurrences in the manufacturing itself, which may cause changes in the production process, or require human reasoning capacity. This would include, for example, changes in the "daily form" of workers and fluctuations in temperature to the extent that they influence the operation of individual machines and workpieces. Changes in the production context which lead to a change of planning objectives on the shop-floor are very important. When conflicts regarding deadlines occur, the relevance of customer orders has to be weighed up; different strategies are required in instances of operating above capacity and in cases of little loading.

The quality of and speed in dealing with an order depends very much on the degree to which the interests of the production workers have been taken into account. This takes in far more than wage stability and regulation of stress; it means preventing monotony by diversifying the work and ensuring interesting and challenging tasks. The knowledge and experience and the direct personal relations between first line management (foremen, group leaders) and production workers remain factors of great significance for shop-floor scheduling, particularly in the context of flexible production processes; they can therefore not be considered as marginal factors which will be made superfluous by new information technology (Hars, Scheer 1990).

Electronic control stations are an excellent means of utilizing and mobilizing this knowledge and experience.[12] The high degree of user-friendliness of the systems on the market predestines them for decentral use. For this reason they should not be employed as a mere appendix to PPC and central manufacturing control systems but rather as active and important elements with their own scheduling areas in the overall system of production planning and control.

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12 See Böhle et al. 1991, for further information and analysis on the categories of knowledge and experience.

IV. CAD/CAM-Integration and Alternatives in Work Organization

The term CAD/CAM and the underlying integration technology have been around for more than 20 years. They date back to technological concepts which originated in the first half of the 1960s in the wake of NC development in the USA. Admittedly, these systems have spread only haltingly so far (Schultz-Wild et al. 1989).

The integration path of CAD/CAM is very broad; it covers all technical aspects of production in a company: from engineering and design to process planning and manufacturing up to and including quality assurance. The breadth of its integration comprehends the entire work-piece spectrum of a company and the associated machining processes. Consequently, CAD/CAM systems integrate the individual technologies of CAD (computer-aided design), CAP (computer-aided planning/programming), CAM (computer-aided manufacturing), and CAQ (computer-aided quality assurance). Together with computer-aided integration of the economically-oriented functions in the handling of orders by PPC systems, CAD/CAM systems virtually form the backbone of a CIM system.

1. Basic System Alternatives

The following chapter will examine the prospects associated with integrated CAD/CAM systems with respect to maintaining or extending skilled production work. As indicated in the introduction, various concepts exist here as well as in the other "integration lines"; these concepts offer a broad scope for design alternatives especially with regard to work organization on the shop-floor.

Basically, it can be assumed that there is a high degree of "elasticity" inherent in the various computer components as far as their basic design and configurations are concerned. Consequently, in theory, a corresponding scope for work organization and work design should also exist; in practical applications, however, this is not necessarily the case. As much as ever, there are many technical limitations - such as, in particular, the often discussed interface problems - for combining virtually any number of different computer components. Besides that, user companies generally have to more or less accept the system concepts predetermined by the vendors and can at best modify them in a limited way in line with their interests since they do not possess the necessary resources, i.e. funds, know-how, qualifications, and time. Due to specific technical features peculiar to the various system concepts, the scope for work organization and work design, which exists in principle, is likely to be substantially limited from the very beginning for the individual user introducing the systems.

This holds in particular for CAD/CAM systems as they tend to link and integrate practically all the "vertical" process planning and technical design functions of a company by means of information technology. Consequently they affect the relationship between division of labour and cooperation at the same time. This concerns in particular the possibilities for organizing the internal division of labour in functional and hierarchical terms. Technical specifications influence the distribution of conception and execution. As a result, there is a limited degree of manoeuvrability both in the practical configuration of machinery and jobs on the shop-floor and in the related structure of skill requirements, which definitely affects the distribution of functions of technological process planning and of the programming of NC machine tools. These functions can either be executed in a organizational structure based on division of labour in one of the offices separate from the shop-floor (process planning or even design department) or else on the shop-floor itself where it can represent a focal element of skilled production work.

These correlations apply less for comprehensively integrated CAD/CAM systems, which the users could adapt to the specific requirements of their company. They do hold, however, for the relatively widespread "sub-lines" in CAD/CAM integration, CAD/NC and DNC (see Schultz-Wild et al. 1989). Whereas in the various forms of the CAD/NC integration CAD systems are linked with NC programming systems for the common use of geometric data of parts, the DNC sub-line generally integrates NC programming systems with the various types of CNC machine control units via the use of a DNC computer. The core function of DNC systems is the on-line transfer of NC programs between the various system components (Weck 1982).

For both types of CAD/CAM integration mentioned above, complete solutions are offered on the technology market. On the one hand, they always require adaptation, modification, etc. to the needs of the company. On the other hand, they offer specific technical features which are associated with a different potential with regard to work organization and job design. Differences of this kind can be found both between and within the individual sub-lines. Typical features from a viewpoint of information technology are e.g.:

- the concrete functional design of computer components;
- the structure and interface of the user programs;
- the form of data organization and data transfer via interfaces,
- and the respective hardware configuration.

If one now attempts to analyze the current and foreseeable offers of CAD/NC and DNC systems[13] on the technology market[14], in a first rudimentary distinction two types of system concepts can be identified:

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13 No further attention will be given to the computer integration approaches with CAQ or with computer-aided systems for process planning because of their obvious

- a concept ***based on division of labour***; and
- a concept which is ***flexible with regard to work organization*** and consequently ***open for shop-floor workers***.

These concepts suggest different ways of dividing the work functions of planning, adapting, and implementing processes between the process planning departments and the shop-floor (Fig. 4.01). The various system concepts are both an indication of the underlying socio-economic conditions of the technological development and the structures of the technology market.[15]

2. The Predominance of System Concepts Based on Division of Labour

The majority of CAD/CAM concepts end up maintaining the traditional division of labour between conception and execution within an organization of work differentiated according to hierarchic-functional criteria. This main path of CAD/CAM integration is obviously determined mainly by large computer manufacturers and system vendors.

There is a marked orientation to large-scale company structures with a high degree of division of labour and complex requirements for manufacturing; this is an indication of the particular impact of the American aero-space industry on CAD/CAM development (cf. Noble 1984). This applies in particular for a number of specialized American CAD/CAM vendors who have had a strong influence on the Western European market for these systems, and partly dominate it (e.g. VDI-N 41 1989). Some French developments in this field point into the same direction.

De facto, these system concepts concentrate on coordinating functions in design, process planning, and on the shop-floor more systematically than was possible with conventional methods. These areas are organized on the basis of a distinct division of labour and are traditionally separated from each other. In addition to coordinating functions, these systems establish a steady and efficient flow of information between the various departments. The central feature of these system concepts based on division of labour is that they integrate an

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heterogenity with regard to information technology, and their only very limited diffusion.

14 Empirical basis of the following argumentation is: the analysis of engineering science literature; seven visits to relevant trade fairs; a total of 21 expert discussions with vendors and engineering scientists between 1985 and 1989; and three engineering expert reports commissioned by ISF Munich (Maier 1986; Grupe, Hamacher 1988; Beck et al. 1990).

15 Only passing attention may be given to these relations and the concrete manufacturer-user relationship developing on the technology market, the respective constellation of the engineering agents, institutions, etc. down to the connected sociostructural conditions (cf. v. Behr, Hirsch-Kreinsen 1987; chapter III in Altmann et al 1991).

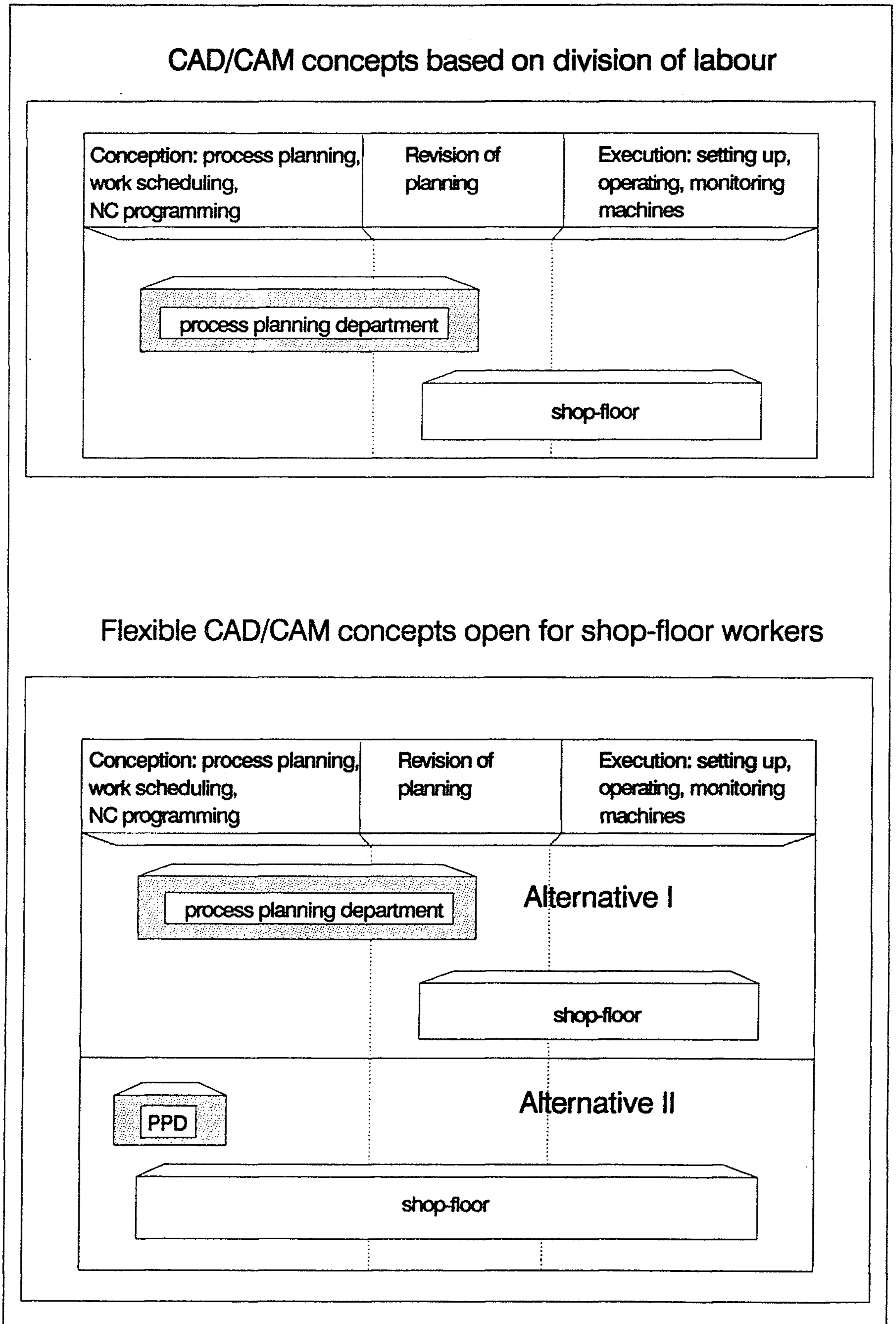

Figure 4.01	**Organizational Alternatives of CAD/CAM Integration**	**ISF 1991**

NC programming system which supports office-oriented operation in some form or another but is not suitable for shop-floor operation.

a) CAD/NC Systems

As far as it is possible to assess the products available on the market, it would seem that at the present time all CAD/NC systems are heading in the direction of an enforced division of labour between planning and programming on the one hand, and execution on the shop-floor on the other. The possibilities of integrating standard CAD systems generally cover NC systems only, which are linked in one form or another to office-bound operation.

This applies to systems where a *NC module is integrated* into the software of the CAD system; this requires a relatively expensive and complex CAD station for programming, which is only suitable for office operation, and not for shop-floor application. According to experts, such a CAD station is too expensive for merely occasional use in programming on the shop-floor. Secondly, because of the system complexity and the design of the user interface in particular, specific EDP and CAD knowledge is necessary. Finally, the shop-floor environment, which is in many ways troublesome, prohibits an installation in this area.

This also applies to CAD systems which in one form or another are linked via *interfaces to separated NC programming systems*. These systems are generally designed to be linked to existing computer-aided programming systems based on higher programming languages (APT and APT dialects) which have often been used for a considerable lengths of time in the companies; these are not suitable for operation on the shop-floor essentially because of their operating logic and operating requirements. Their application demands special training and experience among other things, not only because of the complex program presentation but also because of the high error rate of these systems (Grupe, Hamacher 1988; p. 55f).

In both instances the possibility of reintegrating and maintaining conceptual, and above all, programming functions on the shop-floor is not provided for in the technical concept. On the contrary, the effects of these systems are more likely to mean transferring the programming functions onto the design department (cf. also Lay, Hoß 1988, p. 47ff; Martin 1988).

b) DNC Systems

From the viewpoint of work organization scarcely more flexible is a whole series of DNC systems whose essential technical features also de facto support the preserving of existing structures with distinct forms of division of labour.

Many system concepts seem to rely on integrating existing office-bound programming systems on the basis of higher programming languages with the DNC computers and NC machine tools on the shop-floor. The accompanying deficiencies of an organizational structure based on division of labour are minimized e.g. through improved techniques of simulating programmed machining operations in the process planning department as well as by a number of control and adjustment mechanisms to coordinate between the (source)-programs provided from the offices and optimized on the shop-floor. Associated with this is the frequent possibility to access stored NC programs which may be tailored to meet the company's needs. While e.g the NC programming office has access to all the programs in a central storage, shop-floor workers might have only restricted access to programs "released" by the NC office.

Beyond this, DNC also allows for the utilization of more or less comprehensive functions of production and machine data acquisition. This is often considered a prerequisite for profitable DNC operation. However, it only makes sense within the framework of a work organization based on a distinct division of labour. The goal is to increase the control and planning ability of the process planning and engineering departments "above" the shop-floor. Furthermore, a number of advanced systems still in development envisage the integration of a electronic control station, centralized with regard to the work processes on the shop-floor, in which additional scheduling functions such as process planning or manufacturing control can be carried out as well as programming and its optimization.

Finally, DNC systems are also conceived in various ways as more or less automatic feed-back control systems monitored by a shop-floor control station or the process planning department. Data transfer is regulated according to the respective stage of the work in process, which is passed on via monitoring systems to a DNC or electronic control station. Convenient numeric control systems at machine tools which can in principle be used for shop-floor programming also assume in this configuration the central function of automated data acquisition (PDA) and data exchange (e.g. Marian 1986; VDI, ADB 1987; Morgenweck, Werkmann 1989).

3. Growing Significance of CAD/CAM Concepts Suited to the Shop-floor

Of course the application of CAD/CAM systems based on a division-of-labour concept is encumbered with problems for a variety of reasons. There are two main barriers: first, in a large number of smaller and medium-sized companies, which have only a limited division of labour, such system concepts can only be introduced with difficulties and with a certain element of risk. This applies e.g. to the wide spectrum of tool and die manufacturing. Second, the intensified dynamics of the sales markets call for flexible company structures, and larger companies in particular often still find it difficult to reconcile their prevailing patterns of division of labour and hierarchy with such structures.

Due to these and other reasons, in recent times more and more CAD/CAM systems have been developed which are no longer exclusively based on a concepts of distinct division of labour but rather can be used flexibly with regard to work organization and work design. They offer companies a considerable scope for shaping their work organization; in particular they allow for the execution of planning and programming functions on the shop-floor.

These systems which so far can be called sidelines of the CAD/CAM development path are being promoted by smaller, specialized software and system vendors, partly in cooperation with mechanical engineering companies. These concepts are based on specialized production-related know-how which is incorporated into the development of adaptable systems as well as on the accelerated development of hardware which greatly facilitates increased flexibility in system concepts and their departure from earlier "mainframe solutions".

Doubtlessly, particularly complex machining conditions, e.g. the production of complex surfaces by a multi-axle process which is difficult to determine geometrically, still demand a specifically office-oriented design of CAD/CAM systems. These systems need for example the components already listed, like complex programming systems, elaborate graphic terminals and possibly the connection of the system to a mainframe computer (cf. also Lay, Hoß 1988, p. 54ff). However, these considerations hardly apply any more for most less complex machining processes, especially given the hardware development of recent years. The development is shaped by the increasing application of personal computers, and of efficient micro-computers, the so-called workstations.

a) CAD/NC Systems

As far as the current level of research permits a reliable assessment, there are various indications of a diversification of the CAD/NC integration, which so far was predominantly office-oriented. For some time now systems "suited to the shop-floor" have been on the market. They consist of completely integrated hard- and software for a computer-aided workplace; they incorporate CAD and programming functions and can be linked with CNC machine tools to an integrated CAD/CAM system. Due to relatively simple functional scope and, more particularly, the convenient user interface, the application of these CAD/NC systems is obviously also possible next to the machinery on the shop-floor and close to the manufacturing process. In this case, shop-floor workers can sketch the contours of parts and write the corresponding NC programs themselves (cf. Gangl, n. d.; Trippi 1987).

Furthermore, there are concepts to *increase the flexibility* of previously centralistic systems, but these are only in the initial stages of development. First and foremost, considerations directed towards traditional CAD/NC systems on an APT basis should be mentioned; these rely on the shop-floor-oriented application of computer systems often utilized in the company already, and the corresponding data files. The central prerequisite for this concept is considered to be the "opening" of interfaces between system components; the various existing forms of integrating CAD and NC systems via interfaces open up a range of new opportunities. Generally the goal is to increase the possibilities both for combining programs, data, and the system components, and for facilitating communication between them (Grupe, Hamacher 1988, p. 59ff).

Secondly, more recent concepts of a *direct integration between CAD and the shop-floor* should also be mentioned for which a dedicated programming system is not required. The design data are intended for direct utilization in process planning (Junike, Linn 1986). While in the PC-version, the office-oriented organization of planning and programming is not impossible in principle, direct integration of CAD and a CNC machine tools on the basis of a drawing "appropriate for a CNC-application" (Martin 1988) allows these functions to be executed completely on the shop-floor. Such integration concepts were introduced for tourning operations at the last machine tool fairs (Metav 88 and EMO 89) in Germany (Potthast, Zeppelin 1989; Beck et al. 1990). They were described as CAD/SOP integration (SOP: shop-floor-oriented programming); Fig. 4.02 shows the flexibility of a CAD/SOP integration with regard to work organization.

b) DNC Systems

On the contrary, in the case of DNC systems, system concepts which may be described as flexible or shop-floor-oriented have been available for quite a long time and they are constantly being improved. These concepts comprise a NC system which is not designed exclusively for office operation but is rather a programming system in which the operating logic and the necessary hardware allow, with respect to work organization, a highly flexible configuration of the system via terminals, i.e. workstations and integrated CNC controls. These may be relatively simple so-called program editors which have a limited range of application, or elaborate and universally applicable interactive graphic systems. These DNC systems can be extended step-by-step without obvious difficulties, and adapted to specific company needs which means that they are compatible with any kind of organizational environment (e.g. Hellwig et al. 1983; Zeppelin 1985).

A central prerequisite for the flexibility of such system concepts in terms of work organization is that the various system components have a *uniform user interface* either directed towards the specific control logic of CNC controls or as a universal interactive graphic system enabling the simulation of programmed

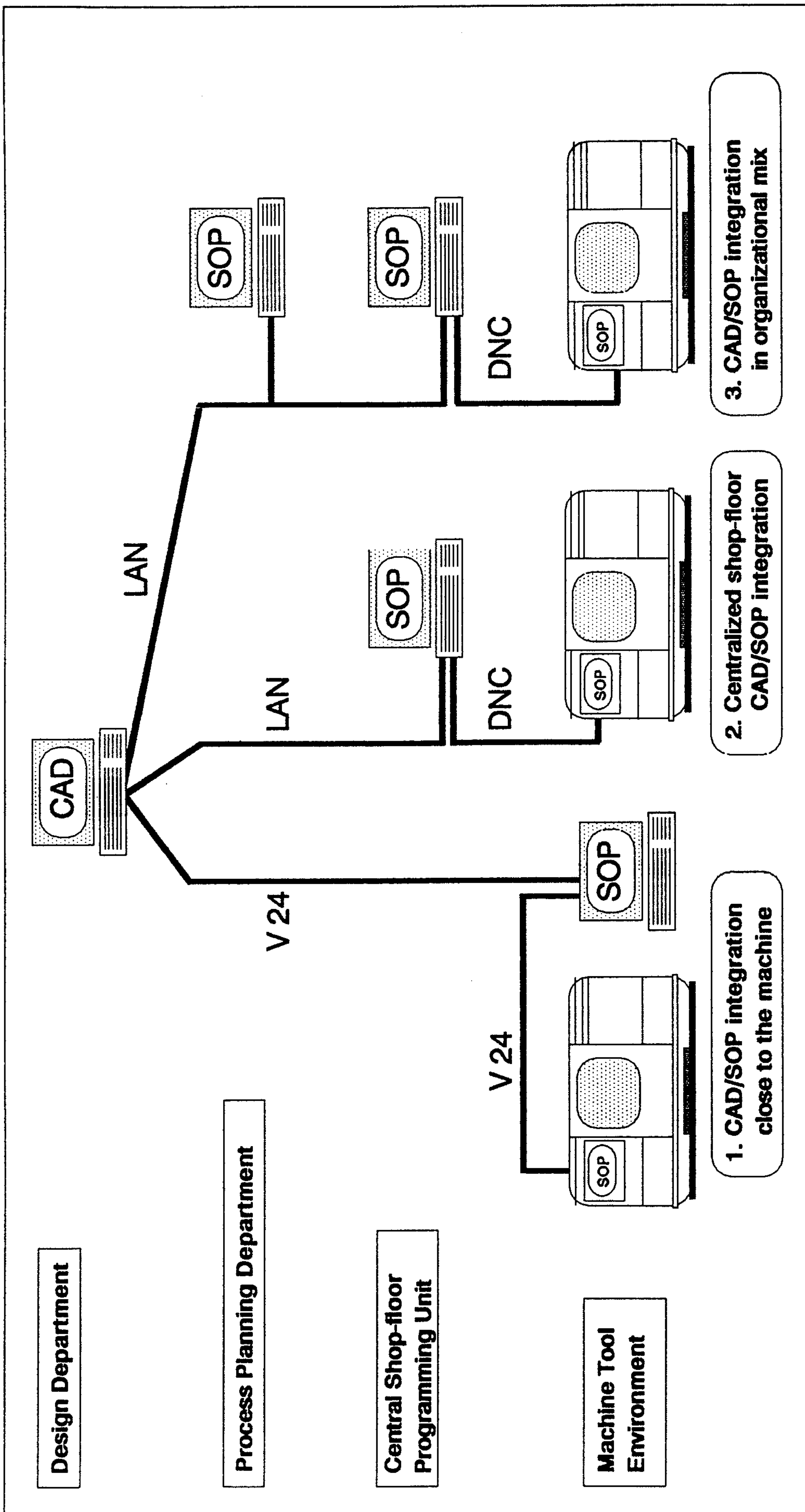

Figure 4.02 Alternatives in Integrating Computer-aided Design (CAD) and Shop-floor-oriented Programming (SOP)

(Source: Beck et al, 1990, p.33)

ISF 1991

machining operations as well (e.g. Morgenweck, Werkmann 1989). In addition to the programming functions, these systems allow for various additional planning functions such as machine set-up planning which reinforces the applicability under different work environments, in particular the extensive use of the system by shop-floor workers.

4. Harmonization of System Concepts?

Without a doubt, the CAD/CAM development in the future will be shaped, at least partially, to an increasing degree by system concepts which are flexible with regard to work organization. In particular the further development of programming systems and correspondingly the reduction of differences between office-bound and shop-floor-oriented programming systems will likely be of significance here. They will be characterized by a progressive homogenization of operator modi following the further development of interactive-graphic techniques.[16] With this presumably lengthy process of CAD/CAM development, the current trend towards modern and extremely flexible CNC controls which run on convenient, directly programmable small computers will be duplicated.

If considerable limitations on the application of shop-floor-oriented systems can be overcome by (re-)integrating planning functions on the shop-floor level, more and more restrictions may be imposed on shop-floor operation under certain circumstances through the progressive establishment of networks to CAD systems. As has been shown, the currently available computer integration paths encompassing CAD systems are practically all only suitable for application in an office-like environment. Shop-floor-oriented integration with CAD systems is still in the initial stages of development and it remains to be seen to what extent this concept will be applicable in the future.

Decisive for the development prospects of these and other CAD/CAM concepts that are flexible with regard to work organization are, however, less basic problems of information technology which are still to be overcome, but rather the future strategies and interests of the system manufacturers and other institutions involved in developing these systems. In this respect, the development prospects of computer-integrated production systems can presumably be described as relatively undetermined. At present, an interaction between various development conditions can be observed.

On the one hand, it can be assumed that the system development is becoming increasingly internationalized and standardized under the aegis of the major

16 The government-sponsored development project "SOP"(= "Shop-floor-oriented Programming Procedures") was one which was trailblazing in this respect. It has provided and continues to provide an impetus towards homogenizing and, to a certain extent, standardizing universal programming procedures (e.g. Herzog 1989; Malle 1989).

internationally active, frequently American computer manufacturers and software vendors. Office-oriented system concepts and those encompassing CAD integration elements will be similarly influenced by this trend. An increasing application of flexible systems will presumably only occur within the framework of the general EDP development in the direction of increasing user-friendliness, etc.

On the other hand, a further differentiation of the flexible systems available to solve a whole range of problems of user companies can be envisaged. This development will probably continue to be borne by specialized EDP vendors and mechanical engineering companies. These system concepts will not only fit the needs of companies operating in specialized market niches such as tool and die manufacturing but will also be suitable for the structures and requirements of the majority of medium-sized and smaller metal-working companies. Of course, the resources of both this developer group and the associated user companies are limited so that it is questionable whether they will be able to cope with the rising costs of system development in the long run. Experts assume that in the future there will be a closer cooperation between manufacturer groups, the large computer manufacturers, and system vendors. It is difficult to predict at the present time what effect this will have on the further development of system concepts flexible for varying organizational environments.

V. Resumé: Technological Preconditions for Skilled Production Work

Now, in the early 1990s, computer-integrated manufacturing technology has not made the inroads into the West German industry as far as anticipated by many CIM advocates. It is showing a tendency towards more dynamic diffusion, however. This applies particularly for small and medium-sized metal-working companies, whereas larger ones show higher rates of applications of computer systems. At present, no clearly predominant concept of restructuring industrial work has emerged. While some companies are attempting to make traditional Tayloristic forms of work organization more efficient by utilizing more computer-based technologies, others are seeking ways and means of maintaining or revitalizing forms of skilled production work on the shop-floor.

Within the context of an increasing utilization of CIM technologies, the concept of skilled and cooperative production work would seem to benefit both companies and workers alike. Whether or not this concept will be able to establish itself depends on certain preconditions.

A comparison of the three basic alternatives of organizing industrial work reveals that the concept of skilled and cooperative production constitutes a highly desirable development direction. This is not only due to its positive effects on the efficiency and flexibility of manufacturing but also because of the prospects it offers for improving the quality of working conditions and ensuring the long-term availability of skilled labour for industrial jobs. This alternative may therefore be regarded as a *guide-line* for work organization for large sectors of the metal-working industry. However, as already indicated, it will be necessary to overcome a number of technical and non-technical obstacles before this option can become a more or less general industrial practice.

One major factor is the selection and utilization of technological systems which support forms of skilled production work or at least do not obstruct or prevent them. In actual everyday industrial practice, however, it is usually difficult to exactly distinguish between the different system concepts outlined above. Not less important is the rapid pace of the advancement of electronic data processing systems, which generates a constant change and an equally fast development in the divergence between the system concepts. Nevertheless, the relationship between technology and work organization, which we have attempted to outline and which is often overlooked, will continue to play an important role in the ongoing and future changes in structures of industrial labour.

One of the central prerequisites for skilled production work is the further development and utilization of computer systems which are flexible with respect to work organization and are open for adaptation to shop-floor conditions. These systems offer the largest possible scope for (re)-integrating conception and execution; this is particularly relevant in respect to CAD/CAM and PPC systems which are directly correlated with the existing hierarchical and functional division of labour in companies and thus with the associated separation or integration of conception and execution. To conclude, we will briefly reexamine the existing integration lines of computer-based technologies to summarize the technological preconditions for skilled production work.

On the basis of our findings and information currently available, we differentiated between two fundamentally different technology concepts:

- first, systems which entail the stabilization of or even an increase in the traditional forms of organization based on a high degree of division of labour;
- second, undetermined (or open) system concepts which can be distinguished by a high degree of flexibility with regard to work organization and by a specific design enabling them to be utilized in the offices of planning or production engineering departments as well as on the shop-floor.

The results of our analysis in respect of this dichotomy may be summarized as follows with regard to the various FMS, PPC and CAD/CAM systems on the market.

(1) According to all available studies, flexible manufacturing cells and flexible manufacturing systems (FMC/FMS) offer a considerable scope for shaping work organization. There are two main reasons for this. First, compared to single machine tools larger systems need more manpower; consequently, they offer more scope for the structuring and organizing of work. Second, there is a continuing trend to manage more and more control functions with the aid of computers. In principle, this results in improved information, planning, and coordination possibilities for both technical offices and the shop-floor. The trend to graphic-interactive user interfaces facilitates the application of new data processing technologies especially on the shop-floor level. As a result, work organization based on these systems may vary between two poles:

- On the one hand, practically all work functions from detailed shop-floor scheduling and programming, management of jigs, fixtures, and tools, to loading and monitoring machine tools can be carried out within the framework of holistic forms of work directly on the shop-floor.
- On the other hand, those functions may also be organized with extensive division of labour; it is possible to differentiate between planning and programming in the process planning departments (conception) and, in principle, more operational functions at the system on the shop-floor (execution). These work functions can even be further differentiated, e.g. into jobs for system leaders, machine operators, loaders, jig-makers, etc.

As flexible manufacturing systems offer considerable variability in work organization, they can be used under the most diverse structures of factory organization. On the other hand, FMS are usually designed to handle specific tasks or work processes and are not oriented to the complete machining of work pieces. At the same time, due to the high costs of these systems management is often not willing to do without centralized planning, coordination, and control.

For these reasons, empirical findings indicate considerable variations with respect to the degree of division of labour; integral structures of production work which assign the whole range of conceptual functions to shop-floor workers remain the rare exception so far. Fundamental alternatives in this direction are more likely to result from the concept of flexible production islands.

(2) Systems of *production planning and control (PPC)* directed towards an overall regulation of complex manufacturing processes in terms of time schedules, production flow, etc. may be designed to achieve detailed *total planning* of all work processes. On the basis of complex algorithms and comprehensive production data acquisition, the objective of such systems is to plan, control, and monitor the work process as precisely as possible. In such instances little scope remains for making decisions on scheduling, job sequences, and use of capacities on the shop-floor. When such PPC systems are employed, production workers are not supposed to handle any orders which have not been pre-planned in detail and which cannot be controlled and monitored from a higher level. Planning and coordination which were formerly carried out by the staff then become materialized within the computer system. Although the efficiency of such systems is questionable in customized and small-batch production, this type of PPC system has been on the market for a long time and is used in many companies. These systems have been improved to achieve a higher degree of flexibility mainly by transforming certain components into modular units while retaining their inherent concept of work organization. Such total planning systems have virtually no scope for introducing skill-based forms of production work, for example, for reintegrating scheduling functions into shop-floor jobs.

Compared to these systems, PPC concepts which provide only for *framework planning* (Manske 1987) are far better-suited to skill-based forms of production work. Systems of this kind dispense with exact and comprehensive advance planning and intentionally provide leeway for planning and scheduling at later stages of the process. Work at the system is restricted to rough pre-calculations and ascertaining certain essential and provisional dates for particular steps of the manufacturing process, and periodically collecting a pool of orders for specific production areas. Detailed planning, i.e. the exact scheduling of order sequences, the coordination between different machine tools, service functions, etc. can be carried out in a number of different ways which are basically selected by the work-force in the respective manufacturing area. Thus, the design of the system is the essential precondition for establishing important planning functions such as scheduling, capacity planning, job sequencing, etc. on the shop-floor, which in turn is a crucial aspect of skill-based production work.

PPC concepts based on a modular design have been available in West Germany for some years now. These concepts have a high degree of flexibility with regard to work organization and are suitable for various forms of framework planning. Whether or not these systems will displace centralized total planning systems in the long run still remains to be seen.

(3) An increasing number of computer-based systems for *manufacturing control or shop-floor scheduling* have been appearing on the market in recent times.

On the one hand, the inherent concepts of many shop-floor control systems are strongly oriented to centralized PPC systems in terms of their hard- and software design so that they represent little more than modules within deterministic systems with somewhat increased flexibility. Due to their complex hardware, a range of functions, which are more or less automated (and, as a consequence, closely linked to a centralized PPC system), and their user interfaces which are often too complicated for shop-floor workers, the operation of these systems depends on specialized personnel in an office-like environment. These systems amount to a centralistic type of shop-floor control, particularly when integrated with production data acquisition (PDA). Compared with traditional systems of central planning, they offer considerable advantages of flexibility, and thus efficiency, yet allow shop-floor workers little scope for further planning. As far as work organization is concerned, these systems are more easily associated with the option of polarized production work than with skilled and cooperative work.

Other systems, not based on the concepts described above, have appeared in recent times and are now increasingly implemented. They have an operational logic similar to the conventional planning board. Such *electronic control stations* are extremely well-suited for application on the shop-floor due to their hardware, fortified for the conditions on the factory floor, their limited automation of planning functions, and their potential for interactive planning according to specific criteria. These systems are able to schedule machine tool operation etc., and provide shop-floor workers with considerable scope for planning. They have a specific, object-oriented, and relatively straightforward user interface, which means that these control stations can be used by shop-floor workers as a tool for controlling smaller or larger areas and establish an information flow supporting decision making about the order status, work in progress, scheduling, job sequences, etc.

(4) *DNC systems* which basically allow the computer-based control of several NC machine tools also display some widely differing concepts.

On the one hand, there is a number of systems based on the integration of *office-oriented NC programming* systems with a central DNC computer and a number of NC machine tools on the shop-floor. Together with a more or less automatic and often integrated production data acquisition system (PDA), these systems strive to extend traditional NC organization to combat some of its current deficiences. As a result, implementation of these systems would converse the trend of a formal transfer of programming functions to the shop-floor, again an important element to ensure skilled production work. Moreover, as they aim at a more rigid formal organization and improved pre-planning, these systems attempt to reduce the need for improvisation, a current feature of shop-floor operations, thus restricting the scope for decision making and action in this area as well.

On the other hand, in recent years a number of DNC concepts have been developed which are *flexible with regard to work organization*, and are therefore also compatible with the preservation of, or even an increase in *shop-floor programming*. They are mainly characterized by an NC programming system which is neither dependent on an office environment nor on the qualifications of specialized technicians. In this respect, there are various types of programming systems with an operational logic and hardware design, which, associated with the appropriate configuration of other system components, allow shop-floor operation. Together with CNC machines programmable on the shop-floor, these concepts establish the technical preconditions for a flexible, shop-floor-oriented DNC application.

(5) Finally, the implementation of CAD/NC systems by linking CAD systems in the design department with NC programming systems is a feature which is establishing itself more and more. It would seem that almost all CAD/NC concepts on the market today are *office-oriented* and lead to an increased division of labour between planning and programming on the one hand, while restricting shop-floor workers to operative functions on the other. So far all alternatives of interlinking CAD systems generally only encompass NC programming systems which are office-oriented due to the cost factor as well as a lack of appropriate information technology. These system concepts do not support shop-floor programming. On the contrary, they tend to transfer programming functions to design departments.

There are, however, a number of *open concepts* emerging which avoid effects mentioned above and allow shop-floor programming even in a CAD-NC integration. First, more CAD-NC systems are being offered with a less complicated hardware and comparatively simple software. These systems are available on PCs or compact workstations and can be used close to or directly on the shop-floor, even in small companies. Second, concepts are being developed to directly link CAD systems to CNC machine tools. These systems implicate that programming may be carried out completely on the shop-floor on the basis of an input of geometrical data from the CAD system into the control unit of the machine tool. Once such CAD/CNC systems have been developed to the stage of implementation, this would represent a major technical precondition for directly utilizing CAD data on the shop-floor.

While the various types of CIM components on the market and in use do not necessarily *determine* the actual forms of work organization and work design, they must nevertheless be regarded as important factors which may either facilitate or obstruct the establishment of skilled production work.

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