Computerised Manufacturing and Empirical Knowledge

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ABSTRACT

What skills are required for working with computer-controlled machines in the manufacturing area? Taking the developments in the machine building sector in Germany as an example, it becomes apparent that a human-centred approach (skill-based manufacturing) offers the companies many advantages over Tayloristic forms of work organisation and automation. Closer observations reveal that skills and qualifications based on empirical knowledge and individual capabilities, such as a feeling for machines and materials, continue to play an important part in the work with computer-controlled machines. So far, however, skills of this kind have received neither practical nor systematic consideration and are regarded as tacit skills in most cases. Therefore it is particularly the use of computer technology which is likely — in most cases unintentionally — to restrict and undermine the essential preconditions necessary for the development and application of such skills.

KEYWORDS

skill-based manufacturing, human-centred manufacturing, empirical knowledge, sensorial perception, computer-based manufacturing

1 INTRODUCTION

This paper is concerned with those developments in industrial manufacturing which are being discussed under the heading of 'human-centred manufacturing', whereby changes in employees' skill requirements are our main concern. The preconditions and limits of the utilisation of information and control technology in the manufacturing process (computerised production) will also be defined and discussed. Particular attention will be given to the role which the employees' 'empirical knowledge' plays, as well as to the basis and preconditions of such knowledge. This in turn provides new findings which are of relevance for the design of work organisation and technology. The paper is based on the findings of a study dealing with the developments in the machine building trade in the Federal Republic of Germany.[1]

2 DEVELOPMENT OF WORK ORGANISATION: TRENDS AND CONCEPTS

In comparison with other industrial sectors in the Federal Republic of Germany such as the automobile industry or the electrical industry, the machine building sector has a predominance of small to medium size companies within it. As the developments to date have shown, two kinds of labour systems have prevailed within most machine building companies so far, either manufacturing with semi-skilled workers, or manufacturing with qualified skilled workers. Job organisation in semi-skilled manufacturing is characterised by a strong division of labour in terms of functions and skills. In companies where the manufacturing process lies mainly in the hands of qualified and skilled workers, the horizontal as well as the vertical divisions of labour are less pronounced. In such cases the skilled workers are capable of handling different machining methods and are also able to take part in the job planning and scheduling for the individual stages of operations of machining.

To a large extent the utilisation of CNC-controlled machine tools has left these manufacturing structures and forms of work organisation unchanged, and the new technologies have been integrated into the existing labour systems.

In the case of manufacturing with semi-skilled workers, this integration can have the effect of maintaining or further increasing the existing division of labour. In companies with skilled workers handling the manufacturing processes, there is a tendency to carry out programming in the vicinity of the machines or at least to assign the jobs of program adjustment and program optimisation to qualified skilled workers.

It is also questionable as to whether a future increased utilisation of CNC-machines and their integration into a comprehensive data-technological control system, and the interlinkage of manufacturing and planning processes (CAD, CIM etc,) will necessarily result in a continuation of these developments. However, there are a number of factors which do indicate that in future, particularly with regard to the European industry, factory structures will be advocated which make use of the wealth of skills and qualifications available and which seek to secure the potential for innovation and operational flexibility. This advocacy concerns particularly the case of the often smaller and medium size companies which allow the scope for action and decision making because of the proximity of the manufacturing process to the shop floor. The disadvantages of the Tayloristic model of work organisation, which arise particularly in the utilisation of modern technologies, as well as the advantages which the companies derive from being able to draw on the skills held by qualified workers would seem to justify this course of action.

3 DISADVANTAGES OF THE TAYLORISTIC MODEL OF WORK ORGANISATION — ADVANTAGES OF PROCESS-RELATED UTILISATION OF SKILLS AND QUALIFICATIONS

Practical experience in the companies and scientific investigations have shown that the Tayloristic approach leads, in the case of the utilisation of new technologies, to a number of problems some of which are mentioned below.

Firms following this approach would suffer from relative inflexibility in terms of the alteration of production batches as well as of the process of innovation. This is due to the fact that every change of a customer order or of a piece of production equipment has first to be modelled in terms of the computer system. In the long run the firm might even lose its capacity for innovation because production knowledge and creativity on the human side would have been wasting away for some period of time. All this is in contrast to market requirements. Existing skills (which especially in Germany are a large resource) would be rejected, while skills which do not exist would be required.

The development of more complex machining centres increases capital expenditure per machine, thereby raising the cost of failures and rejections. This in turn puts more responsibility on the shoulders of the machine operator. Apart from problems concerning production technology, the Tayloristic approach also leads to an increase of burden and risks for the employees, thus incurring increased 'social costs'. Particularly in the context of the humanisation of working life, the negative effects of Tayloristic work organisation have been widely discussed and documented in the Federal Republic of Germany. The discussion has included issues such as the one-sided demand made on employees' skills, the high demand on performance and the limited scope for influencing the decision making process. It has also become evident that such forms of work organisation contribute to health risks and premature retirement, loss of achievement potential as well as dissatisfaction and lack of motivation on the part of the employees. And, finally, companies have met with difficulties in recruiting personnel for such jobs and continue to do so. In many instances it was only possible to engage foreign workers for such jobs. Particularly in the Federal Republic, such effects of work organisation were spoken of as a 'crisis of Taylorisation' and the demand for a humanisation of working life came to be viewed beyond the plant level, in a socio-political context (Böhle, 1977). This also resulted in a government programme for the promotion of practical measures and models of work organisation in the companies as well as support for scientific research on the introduction of new forms of work organisation.[2]

In the light of the facts above, manufacturing concepts which are not oriented to a reduction and elimination of employee skills, but oriented instead towards the utilisation of such skills on the shop floor (human-centred approach), not only offer chances for humanising working life but also provide a number of economical advantages as well as benefits in the sector of production technology. The particular advantages, as Schultz-Wild has shown, are as follows (Schultz-Wild, 1987, Asendorf/Nuber, 1986):

'Process-related utilisation of skills and qualifications can save planning costs and other investments for complex and extremely expensive automation technologies in the hard- and software sectors when workers are able to bridge gaps in the process sequence. In view of the continuously high costs for components of computer-aided flexible automation, the fact that the process-related utilisation of skilled labour can reduce the risks and duration of system failures is of particular significance. The utilisation of qualified, skilled workers who are familiar with the specific manufacturing equipment, increases the latter's availability and reliability. Such personnel can not only prevent disturbances by intervening and correcting the ongoing manufacturing process, but also shorten breakdown times by performing repairs faster, due to the fact that specialised maintenance personnel need not be called upon and waited for. Moreover, the process-related use of skills can also permit a better utilisation of manufacturing equipment, not only with regard to the extent of operational flexibility for various products or product variants within the framework of the given technical corridor, but also in terms of coordinating machine schedules and/or production capacity with the requirements of the ongoing production flow. Finally, the process-related use of skilled personnel in the production process can also result in lower labour costs. On the one hand this refers to the savings in costs arising outside the immediate area of manufacturing for technical services such as work planning, programming, manufacturing control, maintenance and quality assurance in the case of a more centralistic type of manufacturing organisation. On the other hand, the number of workers can be reduced compared to highly specialised forms of work organisation, or those aiming for minimisation of the use of skills, because comprehensively skilled workers are able to replace each other and fill vacancies caused by illness or other reasons'.

In view of these facts it would seem highly likely that a production-related utilisation of skills and qualifications will not only be maintained, but also *further extended and that Tayloristic forms of work organisation will continue to be limited or replaced by other forms* (Kern, Schuman, 1984, Schultz-Wild).

4 CHANGES IN SKILL STRUCTURES: THEORY AND EMPIRICAL KNOWLEDGE

How will skill requirements change if the present development continues to proceed in the direction of a process-related utilisation of skills and qualifications? In what respects will there be differences or similarities compared with the kind of training and qualifications of skilled workers which have prevailed so far?

The studies available to date reveal two definite aspects: there will be an increased emphasis placed on *theoretical knowledge*, particularly on knowledge such as programming, whereas less demands will be made on practical, manual skills (Hoppe, Erbe, 1986, Sontag, 1985).

But there are also studies which show that the utilisation of CNC-controlled machines, their programming, programme adjustments and monitoring also requires the kind of knowledge and skills which skilled workers acquire through on-the-job experience. While skills of this kind are not primarily of a theoretical nature, they are obviously very important when dealing with the new technologies (Dörr, 1985, Kern, Schumann, 1984.) A typical example of this is the kind of empirical knowledge held by skilled workers who have acquired a feeling for handling certain materials, or learned to register and judge the various running sounds of a machine when controlling and monitoring machining processes. Such capabilities and skills play no small role in conventional manufacturing processes. They form an important basis for the safe and responsible handling of machines and materials. Skills or capabilities of this kind have one thing in common: they involve ways of dealing with a job which do not fit into the category of a 'rational' approach to work. It is therefore readily assumed that the employment of computer-based information and control technology and increasing requirements as far as theoretical knowledge is concerned will soon make the need for such skills a thing of the past. But this is far from being the case. In our investigation we tried to elucidate the reasons for this as exactly as possible. In the following we will present the statements given to us by those engineers, manufacturing managers, foremen and workers we interviewed in the course of our research work.

Particularly when working with metal, the properties of the material and the actual machining processes cannot be entirely pre-planned and thus cannot be completely transformed into objective data. This means that the experience and practical knowledge held by employees is necessary in all cases. In this context the companies repeatedly stress that the programmes have to be adjusted to 'actual operational conditions' or emphasise the fact that 'it is not possible to plan everything from the start'. We would like to quote a typical statement by the owner and manager of a machine building company: 'As long as one is working with metal it is impossible to plan everything and one must acknowledge the limitations of theory. CNC-machines relieve the workers only of the physical burdens. Skilled workers remain a necessity due to the inevitable imponderables. During the process of optimisation, the programme has to be adjusted according to the data resulting from different materials'.

Such findings lead us to the question as to whether we are not being confronted with the basic limits of the technical-scientific planning and controlling of production and work sequences affected by the use of modern information and control technology, and whether this does not also show specific limits and essential problems of artificial intelligence.

Such questions, however, can only be answered when we have precise information on the particular nature of the 'empirical knowledge' held by employees. It also requires our understanding of what this knowledge is based upon. To date, there have been relatively few empirical investigations on this topic and therefore it was our objective to pursue this question in a more systematic manner.

5 KNOWLEDGE, ITS FOUNDATIONS AND PRECONDITIONS

We would now like to discuss some of the results of our investigations which are relevant to the present debate. An individual's capability to acquire on-the-job skills and empirical knowledge, such as feeling for material or the correct understanding of certain machine sounds, are the result of a way of working in which sensorial perception and feeling play an important part in coping with the task in hand. This includes having a certain relationship with the materials and tools involved, as well as the pursuit of particular methods and ways of working.

The characteristic of such knowledge and skills is the establishment of a *relationship* between workers and materials and tools which can be termed 'sympathetic'. In this context one speaks of having a personal relationship and an 'intimate knowledge' of a machine, or of 'knowing it inside out'. Handling material and manufacturing equipment indeed requires *empathy and subjective involvement.* In everyday language one often hears that workers 'must get involved with the machine' or should 'feel their way in', thus working with the machine in a similar manner as one would with any conventional tool. It is also important that operations are carried out in such a manner that the individual procedures are not all planned in detail beforehand, but that each completed phase may serve as the basis for planning the next. *Sensorial perception* during the work process is 'holistic' in the sense that there is no sharp dividing line between the individual faculties of seeing and hearing. For example, they complement each other and relate to the individual's overall physical situation. Characteristics and qualities of machines and materials are not registered in the same way as a measuring device or instrument would do, but are 'experienced'. This is primarily what we might term 'participating perception', meaning, for example, the kind of hearing and listening involved when 'listening one's way in' to something, or the kind of feeling and sensitivity required to recognise or understand something by 'feeling one's way into it'. This way of working by no means excludes or interferes with rational thought. In fact, the opposite is true: *feeling* is an important factor in perceiving and sensing the characteristic qualities of materials and objects. This kind of perception is, for the most part, acquired through practical experience.

Of course the usual criteria of rational work and planning have nothing to do with integrating feeling and individual perception into the work process. A more differentiated understanding of what is rational, however, will easily show that the consideration of such factors is by no means 'irrational' but is simply based on a different kind of rationality and logic.

These research findings underline the thesis by which human knowledge and human action are not exclusively guided by the principles and the logic on which artificial intelligence systems are based and towards which they are oriented. The findings also support research and considerations concerned with the *differences* between human thought and sensorial perception on the one hand, and their technological simulation on the other (for example, Dreyfus and Dreyfus, 1986). They not only point towards the limits of computer technology, but also reveal that its application *also* depends on employees making use of skills, qualifications and working methods which do *not* correspond to computer logic and the computers way of functioning. As our investigation shows, it is this factor in particular which leads to a number of new problems.

6 NEW DEMANDS MADE ON THE DESIGN OF WORK ORGANISATION AND TECHNOLOGY

According to the findings of our investigation, skills, qualifications and empirical knowledge and feeling for materials etc. can only be acquired, developed and applied in the working process. This process requires establishing and maintaining an adequate relationship to machines, tools, materials, work processes and sensorial perception. It is in this respect, however, that we encounter a number of problems.

By considering the changes occurring in the machine building sector as an example, it becomes evident that the utilisation of CNC-machines results in changes in the areas of technology, work organisation and personnel policies which undermine and restrict the development of such skills in a number of ways. The causes of these changes are not individual, isolated factors, but an entire syndrome which includes: changes in control technology and the external design of machines (encasements, etc.); flexible deployment of employees; the integration of the machine into the overall manufacturing process. These factors bring about complex changes in the relationship between workers and machines, and the overall work methods and procedures. A number of points may serve to illustrate this: the individual skilled workers no longer have 'their machine', but are assigned to various machines; different processing phases must be planned further in advance, and immediate sensorial experience is restricted by the encasements of the machines and partly by their higher operating speeds, while the individual machining processes can no longer, or only to a minor extent, be immediately adjusted or regulated.

These developments place the employees in a contradictory work situation: they must make use of their empirical knowledge and their skills acquired on the job and recognise faults by certain sounds arising (in the case of tool breakage, for example) and thus avert system failures. The workers must also, in spite of measuring devices and instruments, be able to assess and judge, to 'get the feel of' materials and tools on the basis of acquired empirical knowledge. At the same time, however, the design of technology, work organisation and personnel assignment makes this increasingly difficult to put into practice. Present day skilled manufacturing work finds itself beset with a number of new problems. This is evidenced by the rising insecurity and feelings of being overburdened among workers, as well as the occurrence of mental stress and even conflicts with superiors and violations of safety regulations — for example, when machine covers are removed in order to improve the view of machine action etc. In these circumstances positive actions, such as the reduction of physical work burden and the increase in theoretical knowledge, can certainly not be put to their most effective use.

In the light of these conditions it is not only questionable as to whether the employment of qualified skilled workers is desirable for the operation of CNC-machines. It is equally open to question as to whether their employment in this area will generally establish itself and prove worthwhile, not only from the companies' point of view, but also from the workers' standpoint. According to our research findings, this will *also* depend on whether the kind of skills which are presently being put to good use (and being demanded by the companies) by qualified skilled workers will no longer be regarded as 'tacit skills'. But, instead, such skills will be systemised in the development of information and control technology, in the design of work organisation and personnel utilisation, as well as in the training of workers. In this context the term 'tacit skills' (Wood, 1986) is most telling for, in the majority of cases, these skills are taken for granted, or 'go without saying'. But as our investigation shows, this is far from being the case. If these 'tacit' skills do not find systematic consideration in company practice and remain merely to be taken for granted, this could lead to the gradual elimination of those employee skills and the very empirical knowledge which is of decisive importance for the manufacturing process. Regarding skills and knowledge of this nature as superfluous, now or in the near future, could easily favour a development which could lead to an erosion of important preconditions for the utilisation and functioning of new technologies in manufacturing.

7 CONCLUDING REMARKS

In the social sciences, industrial psychology and work sciences, one finds relatively few systematic investigations dealing with the kind of skills, qualifications and working methods we have discussed in this article. If such skills are at all acknowledged, they generally receive no more attention than being classified as 'empirical knowledge' or as 'tacit skills' and left at that, without any attempt being made to gain a complete understanding of their foundations or the preconditions on which they depend. In our opinion, such a close understanding must be regarded as an important factor in the general discussion on the use of information technologies in the manufacturing process, their effects, limitations and preconditions. In this context, however, the prevailing sociological and psychological concepts must be placed on a broader basis. The following statement by an industrial psychologist expresses this in a very apt manner: 'The prevailing trend in general psychology and the traditional industrial sciences is oriented towards obscuring the very difference between man and machine which is essential in this context. They are attempting to model man according to the analogy of the computer, more precisely, in the manner of a digital, serial computer' (Volpert, 1986). Thus the predominant scientific concepts dealing with sensorial perception are oriented primarily to the cognitive-rational action and a corresponding mode of acquiring information and processing it. In this paper we have presented findings of an investigation which was *not*[3] based on such scientific theories and concepts. In doing so we are able to show that sensorial perception and experience in the working process play a different role in the individual's practical work than is acknowledged by those concepts of information intake and information processing which are of a purely cognitive-rational nature. Complex sensorial perception, experience (visual, auditory *and* physical) and feeling also form an important foundation of cognitive processes and human action. According to our findings, however, it is also important to regard human perception in a general context together with the entire scope of individual action and not to take an isolated view of this factor. The studies available to date, such as the one dealing with the systemic nature of intuitive knowledge (Goldberg, 1985), or the study of the sensorial-physical foundations of human intelligence (Dreyfus, 1972), give too little consideration to the fact that a certain relationship to objects and specific forms of practical work, as we have previously described, are always involved and form a basis of such modes of perception. An important requirement for a further systematic investigation of such connections is, among others, the continuation of the discussion on the differences between human action, perception and thought on the one hand, and the systems of 'artificial intelligence' on the other. As our investigation has shown, it does not suffice merely to discuss the limits of technical simulation and the extent to which human perception can be replaced. It is of greater importance to establish the preconditions on which such systems' capacity to function depends and also to clarify exactly how and where human capabilities and ways of acting and working (which cannot be simulated or replaced by technical systems) will remain a necessity. This also means that technical systems must be neither designed nor applied in such a way that the development and employment of such human capabilities is impaired or endangered. The resulting demands on the design of technology, work organisation and training could only be briefly outlined in this paper. It is necessary to carry out further investigations as well as to compile reports of the practical experience already available.[4]

NOTES

1 This paper is based on research by F. Böhle and B. Milkau (1988).

2 Regarding these developments and, particularly, the negative effects of Tayloristic work organisation on employees, such as health risks caused by extreme demands made on job performance and one-sided, unbalanced work burdens, de-qualification and loss of motivation, please refer to the work of N. Altmann and K. Düll (1979).

3 Our theoretical work continues along the lines of the findings on sensorial perception as they have been established within the framework of research oriented to phenomenology and Gestalt psychology (Straus, 1956, Merleau Ponty, 1966). Our work is also based on research dealing with the systemic character and the practical significance of intuitive knowledge and eidetic and associative thought (Goldberg, 1985, Watzlawick, 1982). Lastly we have also drawn on the findings of epistemologically oriented research on the different forms of rationality and knowledge (Langer, 1984, Polanyi, 1966).

4 Some initial attempts in this direction are evidenced by a design of control technology of CNC-machines oriented to actual human working methods and human working sequences. More extensive considerations on the general design of technology are to be found, for example, in the work of Rosenbrock at the University of Manchester. (For example, refer to H.H. Rosenbrock, 1977).

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