7

LEARNING CURVES IN TECHNOLOGY DESIGN

Klaus Ruth[1]

Abstract: The paper analyses different paths in CNC machine tool design in an internationally comparative perspective. Based upon the assumption that design and use, innovation and production can no longer be perceived as separated processes, it tries to explain peculiarities in the design of CNC technology as the result of the properties of industrial cultural configurations. By applying the analytical concept of industrial culture, different Technological trajectories can be broken up and different learning processes in technology design can be detected.

The analyses lay special emphasis on the developing engineers as important actors within a wider actors network, particularly on the engineers problem solving perspectives and their guiding technical images. Typically the latter links qualification and education structures of the manufacturing workforce with the technology design processes, thus technology design and the anticipated application context are related with each other and treated as an integrated process.

---

[1] Ruth, K. 1996. " Learning Curves in Technology Design" in Banerjee, P. & Sato, Y. (eds.) **Skill and Technological Change : Society and Institutions in International Perspective.** New Delhi: Har-Anand. pp. 175-195

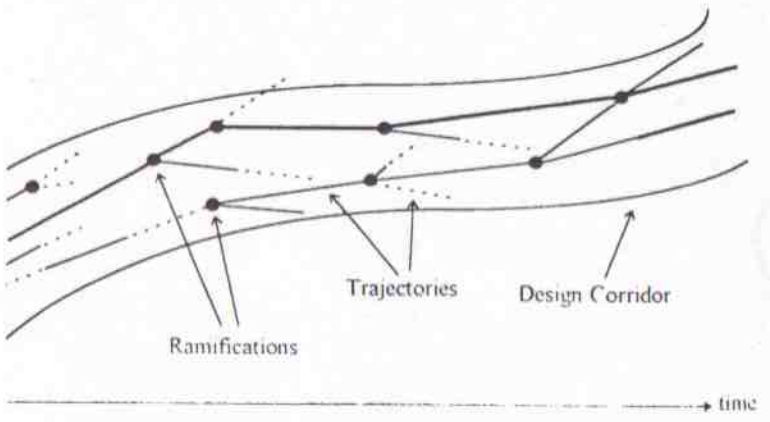
Keywords: CNC machine tool design; Engineering design; Industrial cultural shaping of technology; Shop floor oriented and experience based programming.

Introduction

Until today the use of machine tools, particularly of computer numerically controlled (CNC) machine tools, is one of the best known research subjects of industrial sociology and other related research branches (Adler and Borys 1989). Even the design and development of CNC technology is being widely studied and lots of insights have been produced. The existence of different CNC development paths in various countries is accepted to some degree, but the question that remains open then is, how the different driving forces of the development processes can be explained. This paper suggests that the dynamics of CNC technology development is to be perceived as learning processes. Learning shall circumscribe the fact of further developments that are taking place within the wider or narrower borders of design corridors. This might furnish a better understanding of the driving forces behind and the obstacles to the processes in question.

Technology Design Corridors

When asking any engineer, say a mechanical engineer, why a given machine looks as it does, he will give many reasons which substantiate that strictly speaking the machine could not be any different. On the other hand engineers point with the same emphasis to the significance of technical creativity for the design process (Moritz, Tan 1995). Whereas the former position refers to a more or less secret assumption of unilinear technological development paths with a techno-logic as an inherent motivation power, the latter points to a far-reaching openness of the design processes, which are moreover to a considerable extent formed by individual preferences of the involved actors. Both views are deficient in their own way or exaggerate single aspects of a truly multidimensional problem. The irreconcilable interpretations are facing each other while the more challenging it is to relate both argumentation with each other and to synthesize them. It is the industrial culture approach that tries to redeem this pretension. Industrial culture stands for a research concept that tries to explain the processes of technology design and use by utilizing social, cultural, institutional and psychological factors. These determinants are assumed to be influencing the processes and actors, both in design and use of technology. INFLUENCING is far away from determination in its strongest sense. It rather describes a corridor of possible developments in technology or in other words: a bundle of trajectories (Dosi 1982), each with its own momentum but all in one way or another connected with each other.



Design Corridors

Since the bundle of different development paths is not perceived as parallel fibres of unilinear trajectories but rather as an entanglement of multidirectional developmental steps, the corridor of developments consists of a multitude of technological ramifications (Hellige 1984 and Badham 1986). Especially the social constructivist notion of a seamless web of technical artifacts and respective social actors and processes (Pinch, Bijker 1987) contributed to the insight that there exist actors' configurations (at every given point of the process) which share a common problem view and a common view of probable (and feasible) middle or long-term solutions. A simplified representation of the idea is given by figure 1. The ribbon describes something similar to a technological paradigm (Dosi 1982).

The interesting thing is that paradigms are not static but rather have their specific dynamics which comprise permanent advances by re-interpretation and by uncontradicted integration of newly arising technological advances.

Although the paradigm idea is very inspiring, this model is nevertheless deficient for the purposes of this article, mainly because of two reasons: it is (1) too hermetic in the sense that substantial dynamics cannot be clarified within a paradigm and furthermore (2) the idea of paradigms devises them as a very fundamental basis which is long lasting and has a strong inertia. Since the major idea of this paper is to analyze learning curves, the paradigm concept is despite of its heuristic values not appropriate. I therefore suggest a Corridor model. The main idea of which is that within a given corridor of technical solutions there are several trajectories which are interlinked through ramifications. One technical path is almost never straight through but rather has some branches which are vanishing. But even if these paths may in the short range look like dead end streets, in the long run the underlying concepts might experience a revival. What happens in these cases is that when the technological development has entered a new stage suddenly old concepts can be implemented into these new technical capabilities.

Looking at the German NC/CNC developments on a medium range the following picture can be observed : Beginning with the early imports of NC technology from the U.S. in the early 60s the German developments are mainly following the automation path. This is the main path which rules out all other technological paths/solutions. At every ramification the automation solution is almost always the winner which dominates other designs and lets them sink into oblivion. Nevertheless every now and then one such forgotten creation is rediscovered and then has the power to influence the main path, to give it a new momentum (e.g. record/playback and Handrad, i.e. a hand wheel in Germany). This idea is illustrated in figure 1 with dotted lines. These indicate that the path is theoretically feasible (thinkable), but is not effective in practice, i.e. materialized in technical artifacts. Later in time these virulent ideas might be adopted by the main path. Examples are the revival of the Diesel engine in German car production (Knie 1992) or the temporary resurrection of the Wankel engine in Japan, the rediscovery of V-belts as a substitute for chain drives in motor cycles, and to round up the incomplete listing with an example most relevant for the purposes of this paper: the re-discovery of the record playback in manufacturing with machine tools and the implementation of record playback features into the advanced outcomes of the main development path. This phenomenon will be discussed in greater detail further below.

Before the model of technological trajectories within the boundaries of developmental corridors can be elaborated the eventuality/possibility of learning processes grounded on trajectories and corridors should be understood.

Paths and corridors embedded in industrial culture configurations

Coming back to the introductory statement, a crucial question is how development corridors are constituted or in other words: What makes the different paths take a coherent course so that a given country's efforts in technology development take place within a development corridor?

To find an answer to the question a deeper recourse to the above mentioned industrial culture approach is helpful. To give but a short overview of what industrial culture is about a first look at the aims, the scope and the potentials of the concept is helpful.

Industrial culture can be perceived as a coherent context setting for production and innovation processes or as the GREMI researchers might say: a milieu (Camagni 1991; Crevoisier and Maillat 1991). But unlike the milieu approach industrial culture is configured at various spatial and institutional levels, e.g. national, regional, local and at the level of organizations.

Industrial culture allows us to understand certain phenomena such as technological developments, preferences in technology use or the occurrence of team work as being embedded in a social, institutional and cultural context. The concept furthermore aims at explaining (and assessing) the transferability of engineering (management) concepts from one industrial cultural configuration to another. For clarifying the problems of learning in technology development the former is of superior interest and will therefore be stressed a bit further. Beforehand I will sketch the major influential factors of industrial culture which include attitudes, orientations, social structures and institutions etc. The research up to now suggests the following dimensions to be significant: social institutions, industrial organization, general and vocational education, industrial (and relevant R&D) policy and last but not least psychology. Each dimension can be operationalised into a set of variables (Rauner, Ruth 1990). The most important variables for the purpose of this paper are engineers' problem solving perspectives, role models for designing CNC machine tools and, last but not least, the form and contents of skill formation processes. These and other

determinants developed by the concept are assumed to be interrelated and mutually influencing (and sustaining) each other which makes them constitute a coherent industrial cultural configuration. This industrial culture or milieu for innovation and production allows to give evidence for differences in technology design paths in different countries (or more suitable: industrial cultures) by applying the conception in an action oriented manner. Assuming technical artifacts (like all artifacts) to be the outcome of action processes, the relationship between action and industrial culture is twofold: industrial culture influences acting subjects (like engineers, tech design groups etc.) in a particular field of action (like design processes), influences the action types and in the end shapes technical artifacts which are assumed to be the outcome of the processes (Ruth 1996). Beside this action constitution perspective there is also a reverse process of culture constitution. Even if both are not independent of each other I will concentrate on the action constituting pattern, since this is the heart of the question to be answered here.

Looking at the acting subjects in technology design, in the first instance engineers have to be taken into consideration. Although this is changing while actors from other departments are increasingly involved in concurrent engineering processes, the core work of design is done by engineers and technically skilled staff. These design people are acting within a tensional field between fortuitous, undirected and unpredictable creativity and the strictly rule-following working along a techno-logic with the consequence of uni-linear technology paths. Both hypotheses are insufficient to explain why national developments are far from being random or deterministic following certain paths within developmental corridors. To cope with the problem the industrial culture approach employs the idea of design engineers problem solving perspectives. Problem solving perspectives refer to a typical narrowing of scope which expresses itself in a selective solution finding for technical problems. This idea is linked with the social constructivist concept of connecting technical problems with social groups for whom the problem actually is a problem. These social groups share a common understanding of problems, aims and (potential and feasible) solutions (Pinch, Bijker 1987). Thus the solution finding process can be depicted as a social and cultural interpretation of a given selection of problems which materializes in different technical artifacts. The Synchronization among the designing community can be assumed to be guaranteed by the efficacy of technological role models (Dierkes, Hoffmann, Marz 1992). These role models have guiding and imaging functions which both contribute to the coherence of the designing communities and their problem perception. But how can the focusing on certain problem solving corridors be explained? The focusing of problem solving on certain solutions refers to a concept of Priming (Muller 1993). In the center of the priming idea lies the creative process which is grounded on various actors like engineers, and other technically skilled staff who are in a narrower sense responsible for designing. In a simplified model there can be assumed two Lenses which act like filters. One lens filters and focuses information in its broadest meaning, whereas the second lens handles the problem view of the actors by focusing their perception, and priming their unconscious minds. Thus priming relates to problem solving perspectives and the priming determinants, like motivation, visions etc. are very similar to the influential factors favored by the industrial culture approach.

The advances of the lens model of creative technology design lie in revealing the processes as primed. This is precisely the idea behind problem solving perspectives, but since problem solving perspectives are a shared bias of a Community we cannot adapt to the idea of a focus in the narrowest sense but rather have to assume an idea of design corridors. Design corridors thus are a compromise between deterministic models as the one and only way of designing (i.e. techno-logically driven) and contingency models which presume an unprimed freely floating creativity.

The following section of the chapter will give some empirical backing for the so far developed concept of design corridors and problem solving perspectives by focusing on industrial cultural priming factors like technological (design) styles and role models as well as collective fixed ideas of designers. The analyses will eventually be applied to an idea of learning curves in technology design.

Technology Development as a process of learning along trajectories

In the early stages of numerically controlled machine tools the German efforts in NC development were technically following the US path with a time lag. This was true for the initial NC development as well as for the developments on Adaptive Control (AC) and Direct Numerical Control (DNC). For the mentioned follow-up processes of the German machine tool industry the role model of AC was important but it was not exclusively efficient. Whereas in the U.S. machine tool building automation and off-line programming (in programming offices) were the unchallenged role models guiding the developing engineers design work (Noble 1986), the German situation was contradictory. The model of automation was widely accepted as the technological trajectories' objective and the dominating development path followed the guiding image of automation. But there was a concurrent subdominant trajectory best circumscribed by Manual data inputs (mdi), which stands for programming the machine there on the shop floor by the machine workers. The idea behind the mdi solutions was that programming on the shop floor was both economical (i.e, cheaper than programming offices) and flexible (i.e. programs could be changed very fast on the machine). Evidently these shop floor-biased solutions were not developed in a design vacuum, but were strongly referring to the skill and training structures on the shop floor. The main characteristic of this structure was (and still is) the existence of skilled machine workers (in German language: Facharbeiter). For the developing engineers Facharbeiter thus were the anticipated users of their CNC developments. Skilled work (Facharbeit) thus was priming the developing activities at least of a relevant sub-population of designers in the German machine tool industry. Since Facharbeit is a general user image of engineers, if not as a programmer, then at least as a machine operator, the only difference lies in the task ascription and an underlying concept of economic efficiency (Ruth 1995).

The important aspect regarding German technology developments was that, despite the unchallenged acceptance of the role model of Facharbeiter, a main path following the automation concept with off-line programming as the preferred programming mode was established. To mention but one element of an explanation I want to note the ambiguity of the engineer's efficiency concepts which can be operationalized in different manners and result in different embodiments. This idea will be extended a bit further in the following paragraphs.

Typical examples for the main stream type of CNCs were developed and sold by almost all German machine tool and/or control builders such as Gildemeister and Siemens. Technically these controls were separating planning from execution, i.e. the control concepts did detach an initial planning stage, which ended up with an executable program, from the locally segregated performance on the shop floor. Consequently the human/machine interfaces of the controllers following this conception were unsuitable for programming at the machine on the shop floor mainly because this CNCs required a programming language according to ISO/DIN and, secondly, the ergonomics of the hardware were unfavorable. The anticipated role model of a programmer was an academic or semi-academic personnel who was working in a programming office and thus was cut off from the real (i.e. metal cutting) processes whereas the ideal tasks for the skilled machine operators were testing/maintaining programs, running the machines and supervising the processes.

The centralized programming path was dominating the developments in CNC technology until the mid 80s. The turning point was marked by the increased emergence of shop floor oriented programming devices in the late eighties. As a major difference to centralized programming this concept promoted programming at the machine without using programming languages. Even though this concept did not overcome the functional separation between planning and execution it enabled the machine operators to integrate both functions as tasks to be done by one person. The concept of shop floor programming evidently arose from the same logic as mdi concepts. One might say that shop floor programming is an old concept (of mdi) implemented into new technical potentials. The interesting aspect is that since the occurrence of shop floor programming, the former sub-dominant path is increasingly influencing (and challenging) the dominant path of centralized programming. This is particularly true for the most recent development called computer and experience based work in production which focuses especially on CNC units: The key intent of this approach is to increase the process transparency and to support experience-based knowledge by appropriate hard- and software components, such as joysticks and electronic hand wheels with a dynamic feed back (Bhle, Rose 1993). This development is in a sense an improvement of shop floor programming systems, because a major goal of the experience based systems lies in eliminating the separation of planning and execution by making available devices that allow in-process programming (playback or teach in) and which are at the same time experience based or in other words: which allow utilizing tacit and implicit knowledge for programming CNC machine tools. Since it is fostering experience as a source of production wisdom it supports skilled workers.

Therefore, at least two questions need to be asked: Why is it that there exist two paths of technology design within one industrial culture setting, and second, which were the priming factors for each technological trajectory?

An explanation for the existence of two paths in CNC design can be provided by analyzing the designing actor's problem views and technical role models. The automation path was evidently guided by an automation model which was correlated with the engineer's idea of technical efficiency. These ideas have been adopted as symbolizations superimposing the early NC machine imports from the U.S. Since this automation ideal met with a designing constellation which had a strong affinity to the idea of profitability, it was easily accepted that the machines following the automation/off-line programming path were efficient and economical. Although the protagonists of mdi solutions also felt obliged to the demand of economic and technical efficiency they tried to reach that goal in a different manner: Not saving direct labor cost by eliminating (or at least by reducing) machine work was the developer's goal but orienting towards (a) the weak innovation capabilities of small and medium enterprises (sme) and (b) their peculiarities in organization structures. As a consequence CNCs with shop floor programming features were developed, which furthermore were low-priced and required only comparatively little programming cost since the dedicated programmers were shop floor workers. The techno-social role model of this path was based upon the structural and qualificational peculiarities of sme in metal working industries and on the qualification level of the work force as such, with the consequence of skilled workers (Facharbeiter) as the role model for machine tool users. Since the developing engineers of machine tool builders were focusing their search

for solutions on the qualification structures on shop floor level, their problem solving activities were primed by their view of potential users and the assumed capabilities. The mentioned interaction between qualification structures of the industrial work force and the problem solving processes of technology designers explain the uniqueness of the shop floor programmable CNC solutions in Germany. Embedding this finding in a learning concept, in the long run two kinds of social learning occurred:

(1) Learning along a trajectory, which signifies the embodiment of a concept (or Philosophy like shop floor programming) into the respective technological state of the art. Evidently every stage of technical embodiment brings about repercussions on the concept and thus by means of Technology pushes or sustains the further development of the Philosophy. Thus the philosophy and the technical embodiments are developing co-evolutionarily.

(2) Mutual interference of the major and minor CNC development paths, which indicates adoptions of single features (either technical or conceptual) of the other path. In the actual case of CNC development since the mid 80s the mdi path was more successful in the sense that it influenced the main path and consequently the main path borrowed a lot of shop floor programming features. This could only happen because the industrial R&D policy in Germany supported the shop floor programming concept during the eighties which led to a broad dissemination of the philosophy among the targeted users as well as within the engineering community. And the latter accepted the locus easily because, as an industrial cultural peculiarity, the German engineers are pre-adapted towards skilled workers as machine users. Pre-adaptations indicate the orientation of designing actors into a common drift, in our case the anticipation of skilled machine workers. Different design paths within a corridor thus are caused by the superimposition of this foundation with different

operationalisations of efficiency, profitability etc. Since these orientations are superficial (compared with the general adaptation) the designing engineers can easily accept the logic which underlies the shop floor programming path and eventually integrate selected ideas/features into their designs.

Both learning concepts refer to a phenomenon labeled lock-in which was discovered and developed in other techno-historical contexts (Pinch, Bijker 1987, Granovetter 1992 and Ortmann 1994) but applies perfectly to the case of CNC development. Lock in circumscribes the institutional merging of activity patterns of personal or institutional actors (or actor networks) in technology development and use. Far from being deterministic it encompasses restricted technology development processes which are based upon the existence of two institutionalized industrial cultural determinants: techno-social problem solving perspectives of engineers (or tech designers) and structural peculiarities of the work forces' qualification (as an outcome of the skill formation processes). Evidently the interlocking gadget has to be envisioned as a bi-directional, i.e. dialectical mutual pervasion. To give a (somehow simplified) example: On the one hand the developers of machine tools are adapting their design to the prevailing qualification structures, on the other hand under given interlocked circumstances, there are few incentives for the potential users/actors to upgrade their skill level. Consequently the designers keep their role models and stick to their developing path and the skill structure remains unchanged. Since the lock in often is institutionalized it might get independent of real changes, that means even if the skill structures change the technology design persists. The consequences brought about by the interlocking mechanism lie in a restriction of the technology development processes, i.e. the full scope for design cannot be utilized, because the locking in mechanism prevents the search for technical solutions beyond the corridor.

When comparing the above sketched German case with CNC developments in the U.S. similar phenomena can be found. Due to space limitations these cases cannot be unfolded comprehensively here, in the following I only want to sketch some conclusive remarks on both instances in order to contrast the German scenario.

Analyses of the CNC developments in the U.S. illustrate that here also a lock in mechanism between technology formation and socio-structural/industrial cultural constituents took effect: The CNC developments since the 80s followed a widely unchallenged automation path, there were only very few deviations off the main road, which in any case were only weak alternatives. Shop floor programming solutions give an example of such a peripheral design phenomenon. The main path was following the track of ultimate controls, i.e. highly sophisticated, highly automated solutions (MIT Commission 1989). A very long lasting interlocking of the mechanical engineers problem solving perspectives and the particular needs of the large-scale industries (like car, air and spacecraft) appears when analyzing the last decades of CNC development in the U.S. This configuration could not be broken up with the effect of foreign (mainly Japanese) control builders penetrating the domestic market. Thus, despite the existence of a shop floor programming path and albeit the (real or potential) demand for such solutions created by the huge amount of job shops, the main path was prevailing unchallengedly against the shop floor programming trail. Though the shop floor programming path persisted, in contrast to the German case it did not influence the main path. A major reason for this must be seen in the institutionalized interlocking of the engineer's taylorist techno-social role models with the allegedly prevailing qualification structure on the shop floors. Both, the mechanical and the manufacturing engineers share a similar Leitbild which aims at simplifying the machines to lower the skill requirements on the shop floor in the case of mechanical engineers and tries to keep the operator away from the controls; the machine controls quality and the operator only loads and unloads the machine (Salzman 1992) in the manufacturing engineers instance. Both attitudes express the dominating opinion (which to some extent is a prejudice because there are sufficient industrial sectors which do not fit this description) of a low skill level on shop floors, a belief that perpetuated since the historical rise of the NC technology after World War II and lay the foundation of the automation path in CNC design. The protagonists of the shop floor programming paths could not overcome their role as outsiders neither could they challenge the main stream designers, because their design goals, their user image and their problem solving perspectives could not be accepted by the majority of design engineers whose consensual belief was that there are no solutions feasible beyond the taylorist paradigm. Thus the CNC design corridor was formatively influenced by an overwhelmingly strong and dominating automation trajectory whereas the shop floor programming path was a presumably peripheral and inferior phenomenon. The collapse of the domestic CNC market produced by the invasion of the Japanese control builder Fanuc gives a lot of evidence that, contrary to its self-assessment, the main path itself was oriented to a niche market (i.e. the big companies of the large-scale industries) and produced unsuitable solutions for a larger portion of small and medium sized companies and their particular manufacturing constellations. Moreoever, consistently the supposed shop floor programming niche turns out to be a considerable market share which is still looking forward to being supplied with the appropriate CNC machine tools.

Conclusion

The analysis of CNC technology design processes gives some evidence that the incremental advances are not exclusively indebted to pure technology pushes but are to a considerable degree shaped by industrial cultural factors. These advancements can appropriately be circumscribed as learning processes along technological trajectories. On the basis of a primed creativity the problem solving capabilities of engineers and tech design staff are biased which leads to a canalizing of the development dynamics into design corridors. Under these circumstances the trajectories along which learning takes place can be deemed as a process of embodying concepts (or philosophies) into different technologies at progressive states of the art. However, the detected learning processes turned out to be highly ambiguous: On the one hand the orientation of developing engineers towards the prevailing skill and qualification structures brings about appropriate technological solutions (here: CNCs) which fit the needs, knowledges and abilities of anticipated users perfectly. In the best case the technical artifacts meet the demands of the market, i.e. the requirements of the majority of potential buyers. In the worst case the lock in leads to an orientation towards a little (but financially strong) market segment and neglects the majority of users. In this institutionalized but alienated case of a lock in there is little flexibility in the design efforts and in the long term arises the danger of annihilating the CNC building sector (cf. the U.S. case).

The described mechanism can only take effect when there is a complementary interaction between technology designers and users. In this case learning leads to appropriate technical solutions and by the incremental character of progressing a continuity emerges (which makes the technology paths to some degree predictable); but since the outlined relationship is embedded in and shaped by an industrial culture the pitfall of being too appropriate is quite likely to take effect. In terms of world markets this may stand for a loss of market shares or drawbacks in global industrial competitiveness, because the developed technical solutions are strongly shaped by the industrial cultural design configuration which usually is unique and has special qualities (e.g. the existence of Facharbeit in the German industrial culture and the strong orientation of designers towards it or the lack of a qualified work force particularly in certain segments of the U.S. metalworking industry and the orientation of the CNC machine builders (towards this phenomenon).

Both above sketched variants of interlocking refer to industrial culturally molded learning processes which end up in restricted and incomplete innovation processes or in other words in sub-optimal scooping out of the innovation potentials. i.e. a canalizing of innovation (into smaller or wider corridors) and a loss of a broader scope of thinkable solutions.

Even if the negative consequences of the interlocking effects seem to be outstanding, there are of course some ways out of the trap. Whether or not the pitfall can be avoided depends on the industrial cultural capabilities of merging different technological paths, i.e. the learning aptitudes of the different paths of designing actors from the competing trajectories (the premises of this processes' feasibility have been discussed above). Furthermore cross cultural learning proficiency (i.e. creative adaptions or cross cultural borrowings from beyond the borders of technology design corridors) is not only a means to overcome the interlocking situations but a precondition for establishing new technology design paths or to break through the frame of design corridors. I only want to name some contact points for improvements in innovation which need to be discussed and differentiated further in the future not only to cope with the situation in the machine tool development but to break up interlocked traditions in other technological fields. In need of improvement particularly in the German CNC machine tool building is a strengthening of the marketing function within companies including a fostering of design analysis because both suggestions allow an opening of design perspectives. Furthermore efforts are needed to transform innovative activities into really open, participative and cooperative processes (Moritz, Ruth 1995) because this makes it likely that a reorientation towards strategic innovation perspectives becomes feasible. Tackling the suggested measures inevitably requires a cultivation of all actors concerned: The contents of technical education at all levels (i.e. engineers, technical staff and vocational training) need adjustment towards participation, cooperation and sustainability to enable the mentioned recommendations.

Notes

1. Techno-logic denotes an inherent logic of technology which is assumed to be free of cultural and social influences. and thus exclusively follows the demands of technical functionality (Heidegger and Rauner 1991). Transforming this understanding onto the question of feasibility the techno-logical credo reads as follows: What appears to be technically feasible will be done! And furthermore: The feasibility is not related to the socially wishful but to the technically practicable.
2. Approach explained elsewhere. Please refer to Ruth (1995) and Rauner, Ruth (1991).
3. Even if materialized, these solutions generally are exotic and thus peripheral phenomena with only very limited market success at the time of their initial Invention.
4. The industrial culture approach treats both lines of interpretation as dialectical interrelated, i.e. the action and the industrial culture constituting processes are valid and mutually influencing each other at any given point of time (Ruth 1996).
5. Technically also the plugboard controls must be counted to it as well as the record playback solution.
6. Detailed analyses and comparative interpretations on the German, U.S. and Japanese examples can be found in Ruth (1995). Furthermore Moritz (1994) and Laske (1995) are valuable sources on Japan and on the U.S. respectively.

REFERENCES

Adler, P. and B. Borys (1989). Automation and Skill. Three Generations of Research on the CNC Case. **Politics & Society** 17. 3. 353-376.

Badham, R. J. (1986). **Theories of Industrial Society**. Croom Helm. London.

Bhle, F. and H. Rose (1993). Erfahrung als Leistungsfaktor der flexiblen Produktion. **Technische Rundschau Wissen: CNC-Steuerungen** (special issue). 6-9.

Camagni, R. (1991). Local milieu, uncertainty and innovation networks: towards a new dynamic theory of economic space. In Camagni (ed.) **Innovation networks: spatial perspectives.** Belhaven Press. London.

Crevoisier, O. and D. Maillat (1991). Milieu, industrial organization and territorial production system: towards a new theory of spatial development. In Camagni (ed.) **Innovation networks: spatial perspectives.** Belhaven Press. London.

Dierkes, M., Hoffmann, U. and L. Marz (1992): **Leitbild und Technik**. Edition Sigma. Berlin.

Dosi, G. (1982). Technological Paradigms and Technological Trajectories: A suggested Interpretation of the Determinants and Directions of Technical Change. **Research Policy** 11, 147-162.

Granovetter, M. (1992). Economic Institutions as Social Constructions. A Framework for Analysis. **Acta Sociologica** 1.

Heidegger, 'G. and F. Rauner (1991). **Berufe 2000.** Dusseldorf.

Hellige, H. D. (1984) Di gesellschaftlichen und historischen Grundlagen der Technikgestaltung als Gegenstand der Ingenieurausbildung. In Troitzsch, König (eds.) **Lernen aus der Technikgeschichte.** Düsseldorf.

Knie, A. (1992). **Diesel Karriere einer Technik.** Edition Sigma. Berlin.

Laske, G. (1995). **Eine Branche stÜrzt ab.** Donat Verlag. Bremen.

MIT Commission on Industrial productivity (1989). **The US Machine Tool Industry and its Foreign Competitors.** Working Papers of the MIT Commission on Industrial Productivity, Vol. II. Cambridge, Mass.

Moritz, E. F. and A. G. Tan (1995). Technical Creativity in an International Comparative Perspective. **In Proceedings of the International Conference on Engineering Design, ICED** 1995. Prague.

Moritz, E. F. and K. Ruth (1995). Cooperative Production as a New Paragon Vision or Fiction. In Proceedings of the 5th IFAC **Symposium on Automated Systems based on Human Skill Joint Design of Technology and Organization** held in Berlin, September 1995. Berlin.

Muller, R. C. (1993). Enhancing Creativity, Innovation and Cooperation, **AI & Society. 1.** 4-39.

Noble, D. F. (1986). **Forces of Production. A Social History of Industrial Automation.** Oxford University Press. New York.

Ortmann, G. (1994). Dark Stars Institutionelles Vergessen in der Industriesoziologie. In Beckenbach, van Treeck (eds.) **Umbrüche gesellschaftlicher Arbeit** (Soziale Welt Sonderband 9). Otto Schwarz & Co. Göttingen.

Pinch, T. J. and Bijker, W. E. (1987). The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology might benefit Each Other. In Bijker, Hughes and Pinch (eds.) **The Social Construction of Technological Systems.** Cambridge, Mass.

Rauner, F. and K. Ruth (1990). Perspecives of Research in Industrial Culture. In Karwowski, Rahimi (eds.) **Ergonomics of Hybrid Automated Systems** II. Elsevier. Amsterdam.

Ruth, K. (1995). **Industriekultur als Determinante der Technikentwicklung. Ein Landervergleich Japan Deutschland** U.S.A. Edition Sigma. Berlin.

Ruth, K. (1996). Industrial Culture An Action-oriented View at Innovation and Production. In Rasmussen, Rauner (eds.) **Industrial Cultures and Production. Understanding Competitiveness.** Springer. London. (forthcoming)

Salzman, H. (1992). Skill-Based Design: Productivity, Learning, and Organizational Effectiveness. In: Adler, P. S. und Winograd, T. A. (Hg.): **Usability: Turning Technologies into Tools.** New York, Oxford.