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The discipline of management of technology, based on considerations related to technology

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Abstract

Based on a critical approach to the discipline of management of technology, this paper raises some questions regarding how well suited different perceptions of technology and management of technology are for managing technology in a world enriched by complexity and diversity. It is argued that state-of-the-art perceptions of technology and management of technology have evolved over the years to include more and more issues. However, three current challenges, new understanding of organisation, strategy, and management, point to a number of discussions for management of technology at this point in time. We therefore argue that a perception of technology should take into account the human aspects of technology, the irrational view of technology as socially constructed, should contribute to the new, non-hierarchical organisation, and make it possible to use the complexity and diversity of the business environment proactively. © 1997 Elsevier Science Ltd

1. INTRODUCTION

Man's use of technology is perhaps the most distinguishing factor of *homo sapiens* in the evolutionary race for survival among different species. The human creature is not particularly fast, strong, or maybe not even particularly intelligent! — at least, we know very little about the intelligence of, for example, dolphins or killer whales. Long taken for granted, our use of technology has received little attention in the history of man. However, during the last 40–50 years this has changed and, especially during the 1980s, technology — and the academic discipline Management of Technology — has received widespread attention from both practitioners of management and academics. There are a number of reasons for the emergence of management of technology as a discipline in its own right. There have been (perceived?) changes in the business, political and social environments of firms, R&D spending has grown in absolute terms and as a percentage of GNP, and managers have become concerned with 'core competences' as a source of competitive advantage.

For these reasons, the discipline of management of technology (MOT) has expanded with great speed during the last 5–10 years and confusion reigns regarding what important concepts mean, what the means and measures for technology management are, how problems related to technology management should be solved, and so on. Jones *et al.* (1994) call for a critical perspective on MOT and criticise much of the work done so far, which seems to assume that problems in management of technology may be solved by completely rational models and means. Drejer (1996) takes this discussion a step further by showing that there are different perceptions of management of technology and that these perceptions are based on different assumptions regarding, among others, the idea of rationality. Thus, in order to go one step further in this discussion, we need to resolve a number of important questions related to the discipline of management of technology. Some of the most important questions are:

- What is management of technology?
- What are the challenges to the management of technology discipline?
- How can we deal with these challenges?

In this paper, we shall start by taking a historical view of the management of technology discipline. This leads to a discussion of different perceptions of technology and management of technology, which in turn makes it possible to outline some of the challenges to the management of technology discipline. Finally, the author will make a few propositions as to how the challenges should be dealt with.

2. MANAGEMENT OF TECHNOLOGY: A HISTORICAL VIEW

Above we have sketched a few challenges of MOT theory; we will now take a look at how the theory has evolved over the years.

2.1 Different schools of thought about management of technology

John P. Ulhøi has been one of a few people to take us "towards a theory and methodology of management of technology", under the premise that: ". . . In its present form, MOT has existed since the early 1980s, but its roots can be traced back to the early 1970s under such labels as Strategic Management, Engineering Management, Innovation Management and R&D Management . . ." (Ulhøi, 1992, p. 176). Our own work and literature reviews support this conclusion, as the author has proposed that MOT may be divided into four schools:

- R&D management
- Innovation management
- Technology planning
- Strategic MOT.

The schools have been evolving since the early 1970s (Drejer, 1996). Table 1 summarises this historical account of the MOT discipline.

2.2 The content of the four schools

2.2.1 The R&D management school

The starting point for the R&D management school, as well as the next school of innovation management, is the S-curve phenomenon for technological development. According to the S-curve, technologies are dynamic, they have life cycles and they go through different stages of maturity (Bhalla, 1987). The S-curve phenomenon implies that the higher accumulated investments are in developing a given technology, the higher is the performance of that technology. This has strong implications for top managers, since the development of any particular technology is very expensive but will result in higher performance. Within the first school of MOT, the rationale was to provide funds for R&D (targeted to appropriate developments) in order to harvest benefits from the higher levels of performance resulting from the R&D efforts.

Few researchers have had as large an impact on the school of R&D management and the following school of innovation management as Schumpeter, whose work on innovation and invention has influenced generations of researchers. Schumpeter's work is based on a technology-push assumption. However, two distinctively different perceptions of MOT can be determined from his work (Dosi, 1988; Badawy, 1991). In his early work, Schumpeter contributed heavily to the literature on entrepreneurship and MOT in small, new companies, and this has become a major inspiration for contributions within the school of innovation management. However, in his later work Schumpeter concentrated on management of R&D in large and mature companies — mainly because R&D work became routine in the large corporations after the Second World War (Freeman, 1982).

In the process of technological innovation, science and R&D are closely connected and, as Freeman (1982, p. 213) notes: ". . . There is a strong feed-back loop from successful innovation to increased R&D activities setting a 'virtuous' self-reinforcing circle leading to renewed impulses to increased market concentration . . .". This implies a more or less continu-

TABLE 1. Summary of the four schools of management of technology

	School 1: R&D management	School 2: Innovation management	School 3: Technology planning	School 4: Strategic MOT
Perceived environment	stable, simple and expanding	changing, but predictable	changing and discontinuous	changing, discontinuous, unpredictable, with new dimensions
Scope	manage R&D resources	manage innovation in the entire company	manage technology across the company	manage and integrate technology with other aspects
Issues	people, ideas, funds, culture	conception, invention and exploitation of technology	analyse and plan the complex process of technological development	deal with all the dimensions of technological evolution
Tools for making decisions	technology forecasting, budgeting	Delphi forecasting, technology forecasting, project management of the innovation process	scenario forecasting, technology analysis, planning	strategic MOT, O-T approach to MOT, and integrated MOT

ous process of incremental innovation. This kind of process dominates: "... when industries mature and technological change follows well defined trajectories ... [then] ... economics of scale, barriers to entry, and financial resources become of increasing importance ..." (Dosi, 1988). As mentioned, this process is not necessarily perceived as very realistic in other schools of MOT. However, it is typical of the R&D management school that technological changes are perceived to be predictable and 'forecastable', which in turn makes technology forecasting a management tool of significant importance.

The management of R&D is not normally considered a top management responsibility. R&D is a black box into which corporate leadership places money and resources and harvests benefits from increased technological performance (Bhalla, 1987). However, a few authors have attempted to 'open up' the R&D black box by focusing on the differences between R&D and other departments. Jain and Triandis (1990) claim that R&D should be managed according to four elements: people, ideas, funds and culture. The conclusion is that R&D management in essence is the coordination of the activities of many different individuals in order to optimise the corporation's technological performance against that of its competitors.

2.2.2 The innovation management school

It is also possible to focus on the discontinuous part of the technological S-curve, i.e. radical innovations. This is feasible "... early in the development of an industry, when technology is typically changing very rapidly ... [and] ... uncertainty is very high. As a result, entry barriers are very low, with new companies providing the major innovations, thus becoming elements in the industrial development ..." (Dosi, 1988, p. 15). This was what Schumpeter concentrated on in his early work on entrepreneurship and innovations, which broke with and altered existing standards of production and marketing (Dosi, 1988; Badawy, 1991). As a result, today a number of researchers focus on the entire innovation process from invention to commercialisation. When technological life cycles are short, it is no longer sufficient to focus solely on R&D and expect this to generate sufficient improvement in performance. Instead, it becomes necessary to separate invention from innovation (Jain and Triandis, 1990). The literature agrees on invention as the discovery of something new, while innovation includes the entire process from conception to commercialising. In other words, invention and innovation are related to each other in the following way: *Innovation = Conception + Invention + Exploitation* (Drucker, 1985).

As a result, innovation becomes a much 'broader' concept — not only in terms of the technological life cycle, but also in terms of the corporation, in which the innovation process includes all the functions from R&D to manufacturing and marketing. Within the innovation management school, technological changes are assumed to be rather unpredictable but still predetermined according to the technological S-curve. In accordance with this view, the Delphi forecasting technique was proposed (Roberts, 1981). This technique uses a team of experts to determine the future by asking the experts questions over several rounds while reducing uncertainty in every round by feeding back analysed information to the selected experts (Roberts, 1981; Porter, 1991). This functions as an example of the management tools and methods invented in the innovation management school.

Within the innovation management school, MOT is seen as related to a number of other factors. The 1987 compilation of Sloan Management Review articles (Edosomwan, 1989) clearly demonstrates this fact, as the book contains treatments of subjects such as innovation strategy, entrepreneurship, government intervention, necessary key roles, etc. The contents of the innovation process will not be treated in any detail here, but the reader is referred to the relevant literature. Three compilations of articles (Burgelman and Sayles, 1986; Loveridge and Pitt, 1990; Urabe *et al.*, 1988) are of particular interest.

2.2.3 The technology planning school

The school of technology planning can be viewed as a reaction to an environment which is no longer perceived as simple and stable. Three hypotheses have been proposed regarding the reason for this development: increased competition, sustained progress, and crisis (Savage, 1990; Bjarno, 1993; Dussage *et al.*, 1992). According to the first hypothesis, *increased global competition* leads to growth in R&D spending and decreased product life cycles, which in turn bring about increased competition. This creates a self-reinforcing cycle over ever-increasing competition. According to the second hypothesis, *sustained progress* implies that the time between the discovery of a fundamental process and its application has become progressively shorter over time. In other words, a new situation has emerged in which companies must be managed in a different manner than was the case 30–40 years ago. Finally, the third hypothesis proposes that a *crisis* is under way in which the so-called 'petrol-chemical' technical system is to be replaced by an entirely new technical system.

It is evident that technology has become even more important for the competitiveness of corporations. This serves as the background for the third and fourth schools, since the predictability and simplicity of technological change can no longer be taken for granted — no matter which of the three hypotheses it is chosen to follow. In contrast to the strategic MOT school, the technology planning school is planning oriented and inspired by, for instance, the work by A.D. Little and others, which implies that a set of analytical tools has been developed aimed at planning the management of technology, e.g. technology portfolio analysis and many other management tools (Bhalla, 1987; Bjarno, 1993).

2.2.4 The strategic MOT school

Recently, many authors on strategic MOT have been quick to attribute failure of MOT to the three other schools of MOT. Thus, the starting point for discussing the contents of the strategic MOT school is to examine the problems concerning the three other schools. Inspired by references such as Bhalla (1987), Bjarno (1993) and Drejer (1994), the author has attempted to describe the reasons for the attributed failure of traditional approaches to MOT. This is illustrated in Fig. 1, which illustrates that three reasons are generally attributed to failure of traditional approaches to MOT (traditional meaning the first three schools). These three reasons are:

- *Relatively low rate of technology absorption.* It is often claimed that Japanese competitors have absorbed and implemented technology at a much higher speed than have their American and European counterparts (Bhalla, 1987) and/or that the development of new technologies is taking place at a much higher speed than their absorption (Savage, 1990; Bjarno, 1993). Thereby, technology becomes a competitive factor of strategic importance (Steele, 1989; Porter, 1985).
- *High rate of implementation failure.* Technologies which have been implemented do not automatically turn into business successes. This means that technologies may very well function technically, but fail to yield any significant improvements in business terms (Ansoff and McDonnell, 1990; Voss, 1988).
- *Poor handling of the social consequences of new technology.* Furthermore, it is claimed that implementation of new technology has social consequences which are not dealt with in any adequate manner. This includes training as well as organisational changes at company level (Bessant, 1990; Sun, 1993).

However, on close examination it becomes evident that these three reasons do not provide a sufficient explanation of the perceived failure of the traditional schools. On the basis of the different explanations in the literature, the author has attempted to find the causes for the three main reasons, in order to discuss the rationale of strategic MOT more profoundly. Five factors have been found to cause the three main reasons discussed above. These factors reveal that a number of other issues interact with technology and MOT. The five factors reveal that technology and MOT have yet to reach the top management agenda. In other words, the strategic implications of technological changes are not appreciated in strategic management, which is much too often focused on 'business issues' (Henry and Walker, 1991). Furthermore, understanding between business and technology is lacking, and too often top managers do not fully understand the relations between future products or processes and MOT (*ibid.*). The remaining two factors are related to the organisational implications of MOT and technology. A vast amount of research indicates that implementation of new technology cannot be separated from organisational changes. However, in practice organisations tend to ignore the organisational

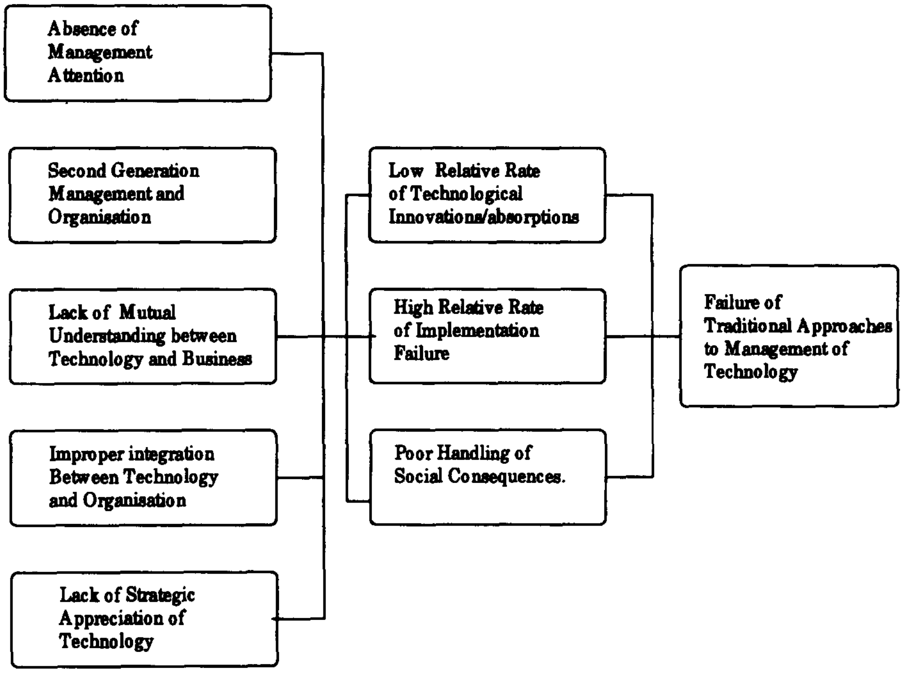

Fig. 1. Perceived reasons for failure of the first three schools of MOT.

issues (Burgelman and Sayles, 1986). According to Savage (1990) this results in the so-called 'second generation bottleneck', i.e. where multiprocessing IT is applied in functional, hierarchical organisations, in which the effects of new technology are diminished (Drejer, 1995).

This discussion leads the author to consider the strategic school of MOT theory. Strategic MOT may be divided into three main streams of research:

1. technology-based strategic MOT;
2. organisation and technology-based MOT;
3. integrated MOT.

Technology-based strategic management of technology. In principle, the label technology-based strategic management could characterise all the approaches to MOT within the strategic MOT school, since the approaches are all 'strategic' in some manner. For example, there is much similarity between Miles & Snow's (1978) model for organisational strategy, structure and process and Bhalla's (1987) framework for 'effective management of technology'. Some of the approaches within the school of strategic MOT are clearly based on technology, and technology is viewed as the starting point for strategic management. Thus, some of the models within this area may be difficult to separate from the strategic management area. Important contributors include Bhalla (1987), Bjarno (1993) and Kidd (1991).

Organisation and technology-based strategic management of technology. A stream of models and frameworks on MOT emphasise the importance of human resources and organisational measures to be integrated with technological development. A number of scholars within this area of research have attempted to achieve integrated changes of organisation and technology, generally claiming that an integrated and balanced approach is the most beneficial for the performance and financial success of a corporation. Important contributions within this stream of research include Voss (1988), Bessant (1990), Sun (1993) and Henry and Walker (1991).

Integrated strategic management of technology. The third string of contributions within the school of strategic MOT attempts to integrate technology and business issues within strategic management — but this string does not take into consideration organisational issues but is based on technology. Thus the models within this area are generally two- or three-stream approaches to strategic management based on (more or less) simultaneous consideration of business and technology issues, and on integrating decisions considering both issues. Important contributions within this area include Dosi (1988), Drejer (1994), Whipp and Clark (1985) and Juhl (1988).

2.2.5 Conclusion regarding the historical development of the MOT concept

The four schools of thought are illustrated in Fig. 2. As the figure suggests, each of the four schools is related to the others by inspiring to refinement of theory and building of new theory. At the same time, each school has developed in its own right.

3. DIFFERENCES BETWEEN THE FOUR SCHOOLS

Evidently, the four schools of MOT are quite different in content and in the assumptions on which they are based. In this section, we shall attempt to link this to different perceptions of what technology, the object of management of technology, may be perceived to be.

3.1 MOT perceptions of technology

In 1987, the National Research Council of the USA published *Management of Technology: The Hidden Advantage*, a research project aimed at discussing some current tendencies within international competition. NRC defines MOT thus: "Management of technology links engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation. ... Key elements of MOT in industrial practice are (1) the identification and evaluation of technological options; (2) management of R&D itself, including determining project feasibility; (3) integration of technology into the company's overall operations; (4) implementation of new technologies in a product and/or process; and (5) obsolescence and replacement." (National Research Council, 1987, p. 15). This is one of a number of explicit definitions of MOT. Another definition within the same tradition is the one offered by Rod. F. Monger in his 1988 book: "... [MOT should] explicitly incorporate mechanisms to deal with management's understanding of new and emerging technologies, organisational and workforce issues, and factors external to the firm. ... [MOT should be] 'integrated' because it ... [should] ... combine the management of organisational issues related to technological innovation and implementation with the technical issues." (Monger, 1988, p. 39). These definitions seem to consider technology as one of the important resources of a corporation. G.H. Gaynor states: "... MOT at the academic level implies: developing an understanding as to how all of the technologies of a business can be integrated, directed towards some specific objectives, and optimised with all the other business resources ... as an example, marketing, financial, and human resource management must be included." (Gaynor, 1991, p. 21).

However, other definitions concentrate on the invention and innovation of technology. This goes for F. Betz: "Management of technology is the timely creation and improvement of the products and productive capability of the corporation. The problem of managing technology ... divides into two parts:

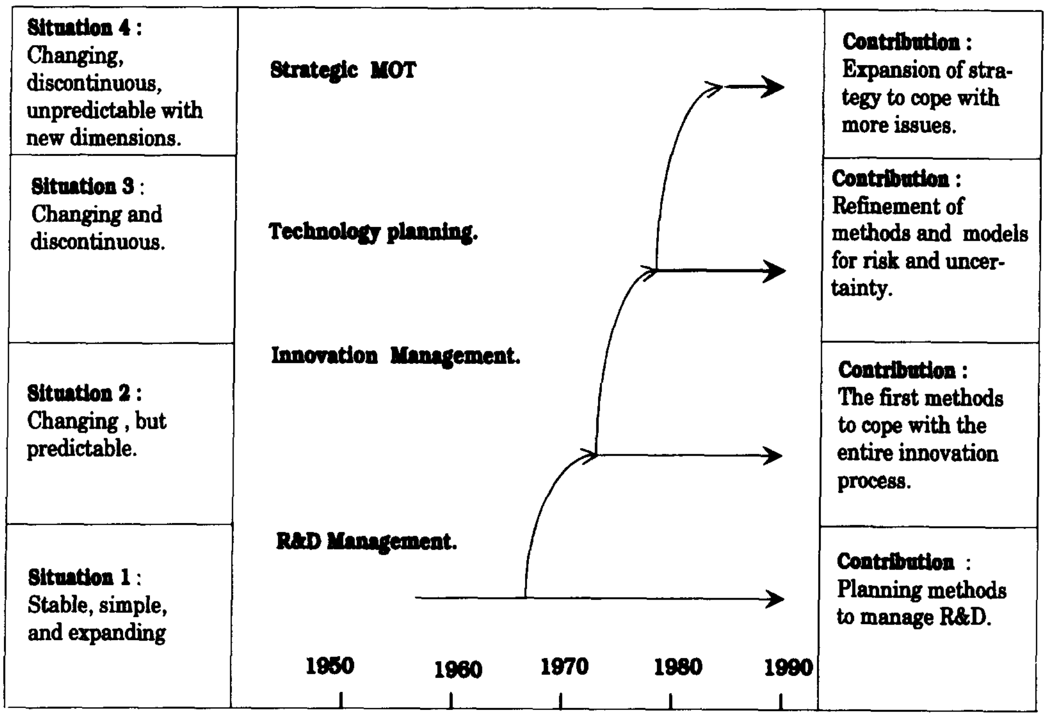

Fig. 2. The way in which the four schools have evolved.

encouraging invention and managing successful innovation." (Drejer, 1995, pp. 1–7), and Tviss and Goodridge: "There is a growing realisation that the adoption of new technology is a highly complex process. Success is dependent not only on the management of change in the technology itself but also upon the changes within the business which are necessary to exploit the potential of the technology. It is these technology-induced organisational changes which management often has great difficulty in coming to terms with. Frequently it involves the culture of the business, its strategies, the organisational structure, managerial attitudes, and personal policies." (Savage, 1990, p. xv).

In a third category comes authors who see technology as a strategic factor and, therefore, MOT as an explicit part of strategic management. This includes S.K. Bhalla: "The integration of business and technology is critical to success in today's environment of stiff competition, chancing social values, and fast development of new technologies. Success in integrating these functions will depend on a corporation's ability to:

- create a mutual understanding between business and technology, recognising each other's needs and constraints;
- recognise the limitations of strategic business planning process;
- incorporate technology as a part of corporate strategic planning process;
- recognise that the effective utilisation of human resources may be the only strategic advantage of a business or corporation." (Bhalla, 1987, p. 85).

Another author who defines MOT as a part of strategic management is M.K. Badawy: "... management of technology is actually the practice of integrating technology strategy with business strategy in the company. This integration requires the deliberate co-ordination of the research, production, and service functions with the marketing, finance, and human resources functions of the firm." (Dussage *et al.*, 1992).

Evidently, there are different ideas as to what management of technology is or should be. But, then, what is technology in MOT?

3.2 What is technology in MOT?

In this section, the concept of technology will be described and defined. This is discussed in a number of references, most notably Kemp (1993), Badawy (1991), Maack (1974) and Wernerfelt (1984), but most references connected with MOT contain one or more definitions of technology.

But then, *what is technology*? As Kemp (1993) notes, there exists a number of meanings given to the word and three different types of definitions are offered (Fig. 3).

- 'allusive' definitions, where technology is viewed as a key factor of success, but where no specific definition of technology is made;
- 'extensive' definitions, where technology is defined but extended to all areas of expertise existing in a corporation, thus making it difficult to differentiate between what is technology and what is not;
- 'specific' definitions, where technology is placed somewhere between science on the one hand and the commercial products or processes derived from the application of scientific knowledge on the other. All processes and products are thus related to the various technologies they integrate, which in turn are linked to science. One might add that most definitions in the references fall into the category of specific definitions.

Maack (1974) includes a discussion of different views of technology that roughly corresponds to the types of definitions above. Three different perceptions of technology are presented: tool, system, and value (Fig. 4).

Technology as a tool implies that man, through his tools, has power over nature, as much over living creatures as over other parts of nature. Man's tools are technology. Normally the word means things such as machines, computers, chips, genetic engineering, computer integrated manufacturing and robotics, but technology means much more than this. As Maack notes, technology also means the methods, processes and techniques by which man is able to make use of nature; i.e., knowledge and experience are also a part of technology. This perception of technology as a tool is very common in the recent literature on technology management; for example, Badawy (1991) defines technology as "the ability to create a reproducible

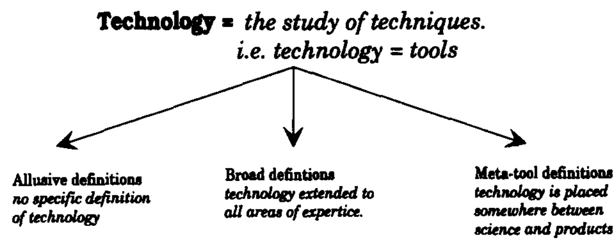

Fig. 3. Types of technology definitions, according to Dussage *et al.* (1992).

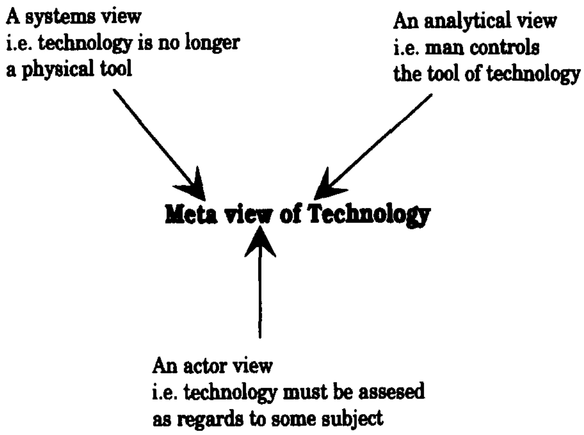

Fig. 4. Types of technology definitions, according to Maack (1974).

way for generating new and improved products, processes and services", surely also a specific definition.

Technology as a system sets off from the fact that technology ('techniques') are no longer physical tools that one can make use of when needed and put away when the job is done. This view implies that technology will affect the user, the task it is used to solve, plus a number of factors that the user didn't intend to affect at the time of using the technology. As such, and remembering that today technologies can be large and complex systems rather than a plough, technologies are among the growing number of things viewed as systems. The systems view focuses on the whole of technology without treating it in detail. This makes it possible to distinguish technology as an entity with or without relations to other systems, and to use many different viewpoints on technology. Furthermore, it is possible to make a detailed analysis by choosing subsystems, e.g. the technical subsystem of a company versus the administrative subsystem.

Technology as value focuses on assessment of technology with regard to some subject — usually without defining technology explicitly. This makes it possible to tell whether a technology is 'bad or good' or even 'better or worse' than other technologies. According to Maack (1974), an example of this can be found within the economic discipline, where measurement of technological changes is defined as "the increases in productivity not explained by increases in capital per man". But many other perceptions of value are possible, for example whether or not a given technology is useful or not for society ('green' technologies). Here one must remember that there are at least two sides to every story, i.e. there exist many different perceptions of value.

4. CHALLENGES TO MOT THEORY

The discussions above make it possible to discuss challenges to the MOT discipline. First, the author will discuss the evolution of the discipline in some detail. This leads to a discussion of the changes that have taken place over the years and of the forces that are at work on the MOT discipline.

4.1 The (resulting) complexity of the MOT discipline

As a result of the historical development of MOT, the complexity of the MOT discipline, *in terms of the assumed uncertainty and simplicity of the MOT task, as well as the assumed manageability of the MOT process*, has increased over time. This is illustrated by Fig. 5. This complexity has increased as measured by the dimensions of scope, issues and the view of technology — dimensions that were used to characterise the four schools of MOT in Section 2. For now, we shall discuss the dimensions in more detail.

The scope of a school within the MOT discipline concerns the extent of decisions in the management of a firm that managers of technology should be involved in, or even responsible for. In the school of R&D management, technology managers are to be responsible for decisions concerning R&D planning and project execution — but perhaps not overall R&D spending as this is assumed to be a strategic decision. Thus, the first school of MOT has a rather limited scope for MOT. Over time, the scope of MOT has evolved from being primarily interested in invention and R&D to include all aspects of technological evolution, including a stake in the strategic management of the firm.

The issues of an MOT school denote the problem areas that MOT is to resolve as part of managing technology. In the school of R&D management, management of technology was limited to the issue of inventing new products. However, in recent years issues such as the organisational aspects of technologies, administrative technologies and marketing have become part of MOT.

The view of technology is a dimension that has been treated in a separate section in this paper, as it is clear that the view of technology inherent in a school will have serious ramifications for the content of that school. From a view of technology as a simple tool, the view of technology has evolved into a very complex perception in which technology is seen in relation to people, organisation, and so on. This may be witnessed by the recent focus on core competences, where technology is only one important factor in the performance of a competence.

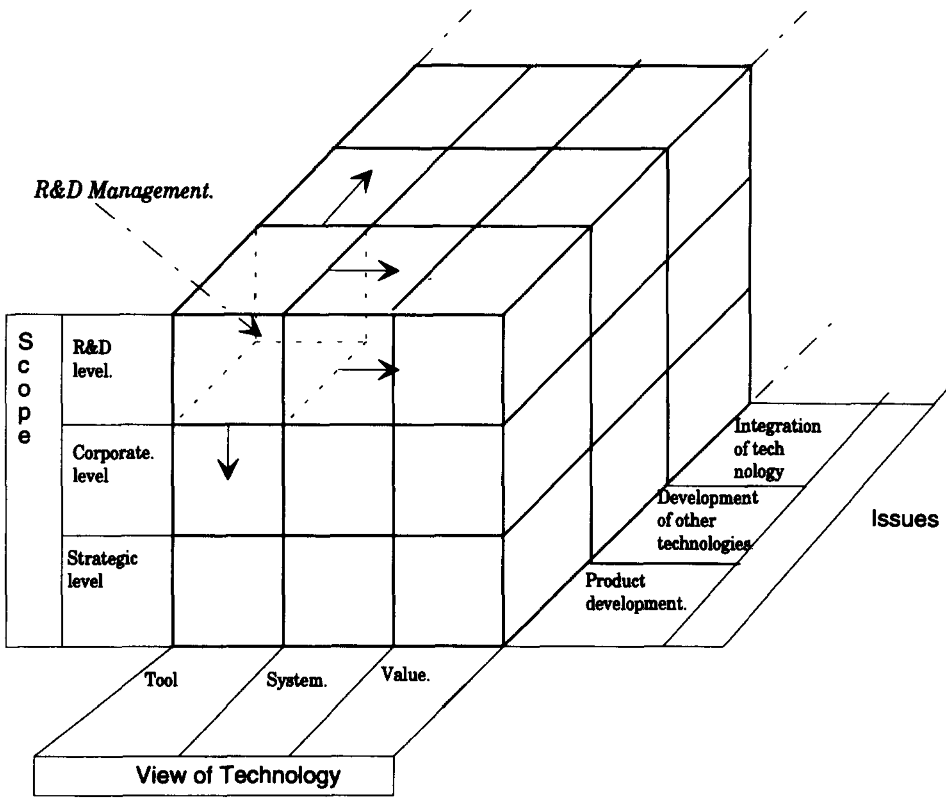

Fig. 5. Evolution of the MOT concept.

In summary, the MOT discipline is much more complex today than it was 30 years ago. It has therefore become subject to disintegration; i.e., a large number of disciplines have become involved in MOT. Today, disciplines such as project management, organisation theory, strategic management, innovation theory, entrepreneurship, technology philosophy and so on are part of MOT as well as being disciplines in their own right. These many disciplines are forces that work on the MOT discipline, changing its content and underlying assumptions.

4.2 Overdue for change?

There are numerous incentives for changing the present state-of-the-art of MOT theory. In the introduction we have already discussed a few of those, i.e. the theoretical fields that contribute to an understanding of technology and MOT and, in turn, drive MOT to change in a 'science-push' fashion. In this section, we shall concentrate on some of the empirical challenges that may change MOT in a 'market-pull' fashion. Apart from the above-mentioned disciplines that affect the MOT discipline, the author proposes that there are a number of challenges perceived by industrial managers and others that also force the MOT discipline to change. These challenges are related to the perception of the external environment in which firms are to survive and manage technology. Table 1 illustrates how each of the four schools of MOT has its own unique perception of the environment and that this perception has changed from rather simple and stable to a perception of the environment as unstable and complex. Most academic papers have an introductory paragraph discussing how the environment of industrial firms has changed towards, e.g., fierce international competition, the need for more customised products, the need for faster delivery and development, the need for lower prices, and so on. But what do these statements mean for industrial firms? On the basis of our limited experience and field research, we have found that three challenges characterise the 'market-pull' on MOT.

The need for a new understanding of organisation is closely linked to a more complex understanding of technology itself. As discussed above, the view of technology has evolved from a simple 'tool' view to a more complex metaview of technology. This, in turn, drives — and is driven by — a more complex understanding of the organisation surrounding technology. In the 1980s many firms focused solely on new advanced manufacturing technology without due consideration of the organisation in which the AMTs were to function. The result was implementation problems, lack of business success, and low worker satisfaction. In the future, it will be necessary to view technology as something that interacts with the organisation and should result in changes in the organisation as new technology is implemented. For instance, CAD/CAM technology offers a chance for rethinking how the work is done in many firms — provided the view of the technology goes beyond that of advanced drawing boards. If it is acknowledged that much information is stored along with the CAD drawings, maybe NC/CNC programming can be done much more easily as the necessary geometrical information about the components is already present prior to programming. This is just a simple example, but many technologies offer opportunities for rethinking work and organisation. In fact, Savage (1990) claims that the lack of progress in terms of new organisational forms is created not by technological possibilities but by managerial paradigms overdue for change. In other words, in managerial thinking we are still stuck in the 'machine organisation' of Fayol and Taylor. But the more complex view of technology, that it is much more than a tool or a machine, makes it possible for us to reconsider the organisation around the technology. In this lies, indeed, a serious challenge for the MOT discipline.

The need for a new understanding of strategy is another important challenge. Traditionally, strategy has been a process of selecting profitable product/market combinations and commiting the firm to action plans for implementing the strategy chosen. However, in a world of great complexity, many firms find that strategy as a top-down approach from business strategy to development of technology is not a viable way to develop strategies. In a world where the window of opportunity for a new product is getting smaller and smaller, it simply takes too long to break the product down into necessary technology — *and develop the necessary technologies afterwards.* It is in many cases necessary to build a state of readiness concerning technological possibilities prior to deciding which new products to develop. Furthermore, some firms also find that it is a great advantage to build on a few key technologies that the firm already masters in developing new products. This ensures a certain base, which in turn reduces the necessary time for product, process and administrative technology development. These examples, however, point towards the need for understanding strategy differently. Business issues, i.e. products and markets, are no longer the only nor the most important issues. Business must be considered along with technology management in order for a strategy to be successful.

The need for a new understanding of what management is constitutes a third challenge. The notion of the rational manager with perfect information is no longer sufficient or effective in a complex environment managing complex technologies. 'Planning is no longer sufficient for managing technology' is another way to present this challenge. The prerequisites for planning are that the necessary information about the technologies and the future is present — and this is rarely the case when we discuss complex technologies in a complex environment. As the life spans of technologies decrease, more and more often firms find themselves in the 'nomansland' between two technological S-curves — a place where traditional methods of technology forecasting are of little value and where planning, therefore, is virtually impossible. But firms need to do something, decisions have to be made regarding MOT. This is the third challenge, to provide methods for this situation.

4.3 MOT in a world enriched with diversity and complexity

Above, the author has outlined some current challenges of MOT theory and its evolution up to its present state-of-the-art; see Fig. 6 for an illustration of the concepts employed in this paper. The MOT discipline is seen as being 'pushed' by a number of other disciplines and 'pulled' by challenges related to the understanding of technology. Along with the discussion of the MOT discipline from a historical viewpoint, this points the author towards some needs for further research within the MOT discipline.

Defining technology and management. Instead of going for the latest buzz-words, perhaps we should recognise that MOT is a part of the larger body of theory related to management and attempt to contribute to this field. This statement has to do with the fact that MOT is already becoming rather difficult to separate from strategic management theory and, perhaps, organisational theory: what is technology as compared to organisation, core competences, and so on? There are great difficulties here. One way to deal with these difficulties would be to make one definition of each concept, all of which are mutually exclusive. Another way to deal with the difficulties is to see work on MOT as work on management, but mostly concerned with technology, i.e. with 'technology glasses' on.

The human element. Much work on robotics and other 'hard' technologies has taught us that the softer aspects related to technology, most notably human users, seem to be more important for competitive impact than do the harder aspects. There thus seems to be a need to emphasise the softer aspects of technology in MOT theory in the future, just as the recent work on core competences has shown. On the other

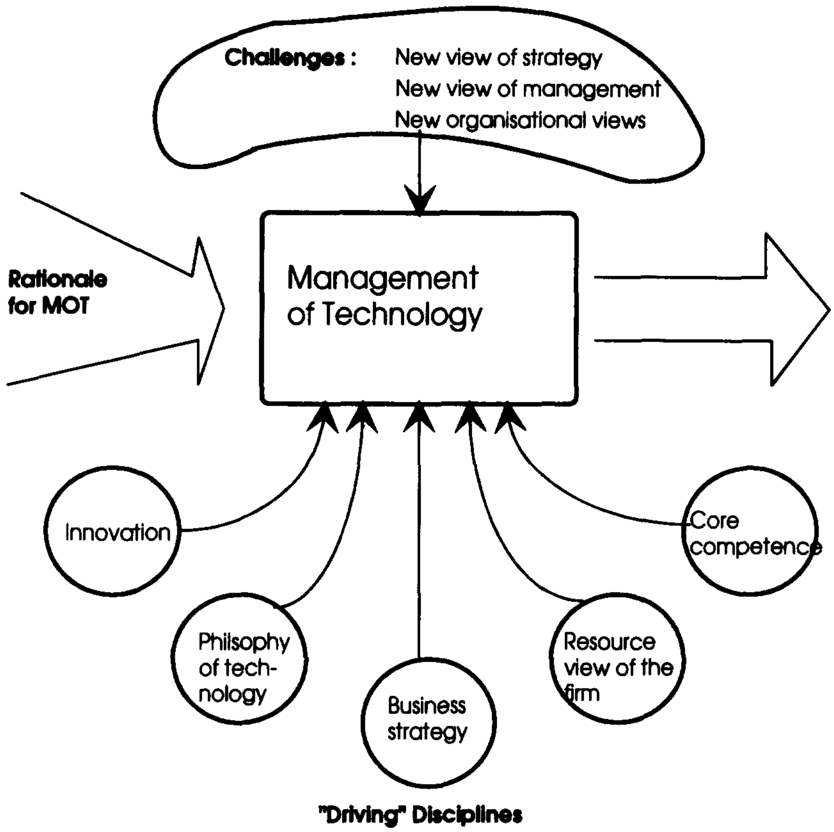

Fig. 6. Concepts employed in this paper. MOT is in the middle of 'science-push' and 'market-pull' forces.

hand, a very broad conception of technology may be semantically difficult to understand; i.e., how can one concept be 'hard' and 'soft' at the same time?

Rationality or lack of rationality. State-of-the-art MOT seems to be highly rational and emphasises planning as the most important technique in managing technology; but considering the pressure for a new formulation of management (e.g. Urabe *et al.*, 1988; Sun, 1993) it could be speculated how this can be incorporated in MOT and technology. One obvious solution is to take into account the view of technology as a social construction, i.e. as something in the heads of human actors rather than an external artefact. Such a view of technology also has ramifications for MOT theory; i.e., the rationality of MOT managers and processes must be questioned in the future.

Commitment versus readiness for action. The discussion of complexity and diversity points to a need for building readiness for action within certain areas of industrial MOT and using the diversity as a proactive tool in MOT. But, in order to do so, a break must be made with the tradition of viewing (MOT) planning as a process of (top-down) commitment. On the other hand, there will always be a need for commitment, i.e. actually doing something, but where and when? Technology may be seen as one of the means of achieving readiness for action as well as commitment in the management of firms.

The new organisation. Many researchers seem to agree that industrial organisations are heading toward a transformation into some sort of new organisation characterised by networking, teams, process view, integration and so on. However, very little is known about how to actually get such an organisation. It is our view that research on MOT and/or management should be very careful not to contribute to a continuation of the classical organisation, e.g. by assuming tight coupling when loose coupling is possible, if this is not an explicit aim of the research. In other words, there is no need to invent the classical organisation one more time in a 'work harder' fashion, but rather to use technology in a 'work smarter' manner.

What is a normative contribution, anyway? The final issue is mainly directed at us as researchers and concerns our part in interaction with industrial firms. First of all, we cannot make value-free experiments on MOT in practice; i.e., field studies cannot be context-free and without influence from us as researchers. This creates some problems on abstraction and on how to generalise findings: caution is warranted. Furthermore, by taking an active part in experiments within the context of firms, we become involved in action research. How can we make sure that we still reflect on our findings and ensure a minimum of justification? What kind of justification is to be ensured?

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