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Fascicule 5
TECHNOLOGY MANAGEMENT
ON LARGE CONSTRUCTION PROJECTS

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Groupe Bagnolet

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RESUME

Le management technologique suscite une attention accrue en raison de la complexité croissante de la production industrielle. Son application à la construction semble être particulièrement adaptée, du fait du grand nombre élevé d'acteurs aux logiques diverses et qui déploient leur compétence technologique de façon individuelle lors des multiples décisions du processus, de la conception à la réalisation.

Le concept de management technologique s'inspire de différentes théories économiques, organisationnelles et sociologiques, chacune représentant des éclairages spécifiques sur la technologie. Il peut aboutir à des recommandations opérationnelles tirées de ces différents points de vue.

Cette contribution présente ces théories à partir des questions générales et spécifiques auxquelles le concept de management technologique tente de répondre. La deuxième partie illustre la démarche à partir de quelques questions technologiques qui se sont posées lors d'un grand projet : le *Storebælt* au Danemark.

INTRODUCTION

An important aim of this paper is to discuss and develop the concept of technology management in relation to the empirical field of construction projects. Technology management constitutes one of the transversal research themes treated in the case studies of the Groupe Bagnolet[1]. As a common framework these themes firstly act as an interrogative guidance to the decomposition of large projects. Secondly and subsequently, analytical and methodological problems enlightened by the empirical reality of construction should imply a review of theoretical aspects inherent in the themes.

The major problem attached to the notion of technology management as a research theme is represented by its prematurity. It does not exist as an unambiguous management term in general industrial operational practice. In construction it is by and large unknown. Nor does its underlying theoretical framework appear to be adequately defined. In other words at this stage we could be dealing with what Kuhn characterizes as a concept in its *pre-paradigmatic phase* (Kuhn 1973).

If we, however, regard management of technology as a fundamental function inherent in technology itself (although in practice not recognized as such), it might also be argued that we are witnessing the third phase in Kuhn's model: the accumulation of anomalies leading to a conceptual crisis, and eventually, in the next phase, to a shift of paradigm for technology management. Indeed, the extensive range of technology originated problems encountered in the large construction projects, which have been studied by the group, is adding strong support to this idea.

The first of two main sections in this paper will discuss questions concerning the development of a modern technology management concept. Initially a number of relevant management perspectives are considered in order to identify corresponding elements of theory-based technology concepts. The central theories and their derived assertions concerning technology management criteria are then summed up in a schematic theoretical framework. Hereafter the general characteristics of construction are examined from the point of view of serving as an empirical field for technology management analysis, and a set of questions relevant to the interpretation of technology management problems are raised. In the second section the technology management theme will be associated with the empirical properties of a specific, large construction project, the Great Belt Fixed Link. Finally on this basis the concluding remarks will point to the main theoretical problems and their practical implications for the introduction of a technology management discipline in construction.

DEFINING ELEMENTS IN TECHNOLOGY MANAGEMENT

Technology management combines engineering, scientific and managerial disciplines in planning, development and introduction of technological capability with reference to the elaboration and implementation of the strategic and operative goals of an organization (National Research Counsil, US 1987)

The short, less bureaucratic and widely used version of this definition merely states that *technology management* is the implementation of technological conversion from one level to another.

A Danish centre of technology management studies[2], recently established in collaboration between the Technical University and the Copenhagen Business School is operating on a conceptual basis which is emphasizing the importance of *interdisciplinarity* in technology management research, thus searching for ways of combining the scientific paradigms of the two participating environments.

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[1] The Groupe Bagnolet performs comparative studies of international construction projects on the basis of 5 thematic perspectives: public policy, strategic management, technology management, project management, and employment and labour.

[2] CISTEMA: Center for Inter-disciplinary Studies in Technology Management (Presentation, Copenhagen Business School & Technical University of Denmark, 1994)

In **technological research** the focus is increasingly upon the different ways in which narrow technical problems are integrated with ecological, societal and social conditions and changes. The challenge has up till now mainly been to comprehend such "external" conditions in the technical designs and furthermore through the organisation of institutional frameworks to provide incentives for firms to incorporate these conditions in their decisions on technology.

In **business economy research**, however, the focus has lately rather been upon technology as a new knowledge resource, possessing radically different qualities from traditional economic resources. Some authors have even seen this as a reason for reformulating central areas of the business economic disciplines (e.g. Kreiner & Mouritsen 1992)

In their logical conclusions the technical-scientific assignment is to develop better technical solutions under new ecological, societal and business economic conditions, while the business economic assignment is to develop better firms and management tools under new economic conditions.

Even though this contrast might, to a certain degree, seem artificial it is also appropriate in order to specify the interdisciplinary assignment: the relationship between the two perspectives, "technology as solutions" and "technology as a ressource", is dialectical. Maintaining and refining this dialectic is exactly what the interdisciplinary technology management research should be doing, thus avoiding purely undialectical and one dimensional understandings like, for instance, the subordination of technical ambitions under the rationalism of a business logic, or like the blindness to business economic realities in a technical fascination.

RESEARCH PERSPECTIVES WITHIN TECHNOLOGY MANAGEMENT

Following the idea of interdisciplinarity described above research into technology management issues could comprise the following perspectives:

- the firm perspective

  covering the problems of the firm in relation to new technology. This does not in advance delimit the empirical field of research. External and internal conditions, and phenomena on micro as well as on macro level might be studied, but the *focus should be the firms' handling of the "technology situation"*.

- the management perspective

  management is a function, not an hierachical level or a group of persons. This function includes choices and decisions of the firm, its development of strategies, the formation of experience and the firm's utilization of this in future situations of managerial action. Many different theories deal with the "who" and "how" of management performance.

- the technology management perspective

  the products of the firm, their development and production represent the point of departure for studies of technology management. Technology management includes the choice of solutions to technical problems on the product and process level under varying limitations. Furthermore it includes the development of the firm's business, strategy, structure and routines in a way which ensures an expansive and constructive utilization of the knowledge resources.

- the social construction perspective

  the "reality" as it presents itself to the firm in relation to new technology has been created through social processes. The firm does *not* act on the basis of objectively defined external conditions, goals, problems and solutions. Rather *the firm experiences or defines* these matters in a way which can be generated in many different ways and by many different social forces.

- uncertainty, dynamics and emergence

  the study of technology management must focus on the post-industrial society and the kind of difficulties, it implies for traditional forms of rationality. Uncertainty is not an imperfection but a basic condition in running the business. Actors and firms enter into interdependent but loosely coupled systems which develop dynamically. Consequences do not alone originate in design but also in different historical, contextual and institutional matters. This gives the development a less deterministic and predictable character.

- case studies as empirical focus

  pointing out the importance of historical, contextual and institutional bindings case studies must be the natural empirical focus. More than merely deducing general empirical results and conclusions, the ambition is to look for generalizations in the theoretical approach to technology management.

As indicated in the introduction the idea of investigating technology management over this wide range of levels also implies a multi-paradigmatic approach in order to interpret the rationale of management actions observed. Furthermore it is provisionally suggested that the development of an operationally consistent technology management concept should consequently incorporate contributions from more theoretical paradigms.

Table 1 illustrates a structuring of theories, which all but from varying perspectives define technology as a central analytical object. Elements of the scheme are briefly resumed below (from Clausen 1996) and then drawn upon in the second section of the paper, where a specific construction project is being studied in order to accentuate the inherent contradictory consequenses of present handling of technology.

In *industrial economics,* technology is a central parameter of competitiveness. The firm must act upon structural conditions in the sector and in the market. Within this framework technology management roughly aims at detecting and choosing the specific technology, which contributes maximum value to the firm.

Competitiveness is observed in a wider perspective within *innovation economics*, focusing on firms' problems in order to gain access to new technology and to destroy obsolete technology. Thus the qualifications of staff, access to knowledge, relations to suppliers and authorities' regulations become essential elements in the development of innovative technological capability.

The actors and organisational structures in firms are raised as subjects in *organisational theory*. Here technology management becomes a question of how the organisation allows for new assignments and prepares for education and learning processes. Unfortunately, in traditional organisation theory explicit actors for managing technology are rarely appointed. This problem area is rather occupied with the most efficient adaptation of the organisation to the demands of new technology.

If, however, the firm is looked upon in a society perspective it is necessary to turn to *industrial sociology*. This theory is emphasizing the technology manager as a performer of functions on a societal level. Thereby technology's consequenses for working conditions, control, power relations and policy come in focus. Technology management then could be a question of developing employees' participation in decision making or of exposing pros and cons of different production concepts.

The influence of the broad variety of actors on the shaping of technology is illustrated by the *new technology sociology*. Contrary to industrial sociology's focus on the determining influence of structures, the new technology sociology is considering technology as «socially constructed» through different actors' interpretation of problems and solutions. Technology management then becomes a question of negotiations between actors in order to create compromises and alliances about the shaping of a technology and its properties.

TECHNOLOGY MANAGEMENT IN CONSTRUCTION

It is well-known that construction products are one-off products characterized by loosely coupled organisations as well as extreme high demands for technological and financial flexibility. In particular the *construction management* and *project management* disciplines are claiming to be able to eliminate technological problems and to operationalise technological innovations under these conditions.

But the internationalisation of the market orientation, (which amongst other things leads to a diffusion of strategic partnerships) seems to be exposing the limitations of management tools in construction firms, basicly because the nationally and culturally agreed conventions concerning managerial rationality are being devastated. In order to obtain an alignment of the empirically recognized areas of management with the above illustrated theoretical structuring of a technology management concept, the following themes could be studied and analysed in construction projects:

- **processes of learning in production and management**. This is of major importance to the competitive advantage of the construction firm as the conditions for production and management changes from project to project. Consequently in practice (and often informally) decision authority has been delegated to low organisational levels. This, however, is counteracting the tendency towards still more sophisticated and formalised planning and management systems. How do firms of different nationalities handle these phenomena and how is management information interchanged in the organisations?
- **routines to mobilise a know-how readiness about technological alternatives.** The construction firm for instance organises this in changing constellations with consultants and suppliers, based on informal national contacts. On an open international market this network is perhaps non-existant or at least based on risky assumptions. Do the upcoming demands on company certification and financial capability overtrump the technological competence?
- **access to components, technological know-how and innovative experience** in continuation of no. 2 (above). To what extent is this a deliberate motive of the firm for entering a joint venture, or is simple market access the focus? The traditional project management as it is performed in large construction projects is dominated by the legal and economical relationship between the actors. Furthermore the formation of construction project organisations seems to reflect optimum imperatives of transaction cost theory which, it might be argued, leads to an atomisation and draining of the production process as far as technological competence is concerned.
- **The relationship between construction firms and public authorities**. The importance of this aspect has definately increased with the EU regulations. Will for instance the different directives eventually accelerate a technological standardisation - and in what sense? How are environmental aspects influencing the choice of technology? And health and safety standards? Not least the latter differ much from nation to nation.
- **Development of new products and markets under internationalised conditions**. This is perhaps the most important theme as the - although temporarily - freezed external relations of the firm in a joint venture are probably a deliberate stategic action in order to exploit these conditions. Finally in this context the question of technology management in complex intercultural surroundings and also the problems of technology assessment and -transfer to alien areas must be raised

TABLE 1: DECOMPOSING CENTRAL THEORETICAL PARADIGMS FOR A TECHNOLOGY MANAGEMENT CONCEPT

Source: Clausen, C., Bruun , P., Pederse, J.L., Bonke, S.: Introduction to technology management (Master course), Technical University of Denmark, 1995.

Theory	Subject/Criteria	Technology concept	Actors/participants	Structures	Action/methods
Industrial economics *(Porter)*	The competitiveness of the firm. Market relations	Technology is available. Technology as «black box», externality and central parameter of competitiveness	The firm	Industry structures. Market structures	Technology scouting. Forecasting. «Early warning». Analysis of value chains
Innovation economics *(Freeman, Grant, Bessant, Georg, Karnæ)*	Competitiveness in a wider perspective. Innovation capability. Technology resources. Knowledge base	Friction and barriers to choice of technology, limited rationality and knowledge. Internal and external knowledge, «innofusion», trajectories, paradigms	The firm, supplier, user, institution, state	Institutions, networks between companies. Resources and knowledge base of the firm	Develop capability and alliances (i.e. supplier/user). Learning and reflection. Technology strategy. Resource based analysis of strategy
Organisational theory *(Barley, Hildebrandt)*	Adaptation of the organisation (Adaptation of the technology)	Technology is taken as given	Actors within the organisation: management, departments, groups etc.	The structures of the organisation; competencies, status, division of labour etc.	Assigning of tasks, training, structuring, policies, negotiation and learning within the organisation
Industrial sociology (Olsén, Hvid, McLoughlin, Clausen)	Societal consequences of technology: employment, qualifications, working conditions. Societal driving forces and mechanisms in technology choice	Technology is developed in interaction with the society	Actors in the firm, representatives of different groups in society: Management, trade union representatives etc. Parties on the labour market, the state	Societal structures, labour market structures and power	Analysis of consequences and driving forces, interests and decision making, processes, participation, negotiation, dialogue, education and training
New technology sociology *(Bijker, Cronberg, Hughes, Andersen)*	Formation of technology. Social construction of technology	«Seamless web», Technology and society are inextricably connected and cannot be clearly distinguished	All relevant social groups	Structures are formed («socio-technical ensembles»). The utilization of power is more important than power resources and interests	Formation of alliances between actors. Enrolment of new actors, establishing fora for negotiation

In principle, the investigation of these five issues could serve as an indication of technology management awareness in construction, represented for instance by the managerial attitude of the project organisation partners towards the potential mixture of technology originated problems and opportunities. Obviously, research methodology would then have to be further developed.

Rather than demonstrating an ideal full-scale analysis of these issues the following section has a more limited intention of exploring the applicability of elements from the the suggested basic theoretical framework, and then developing only some central lines of arguments forward to answering the above raised questions.

TECHNOLOGY MANAGEMENT ON THE GREAT BELT FIXED LINK

On large infrastructure projects the superior choice of technology is evidently taken within the environment of political and economic interests.[3] The choice is an outcome of alliances contracted by different actors and their power relations. The available competence of technology experts is not taken into account for an overall assessment of each technological alternative. Rather representatives of these alternatives are applied «as experts» by political decision makers for boosting the reliability of their arguments. Thereby firms are on the other hand given the potential to influence the technology choice in a direction adequate to the actual or strategically planned capability of the firm. A position of power is achieved by distributing confirmatory information to the political forces working for the corresponding solution.

The final choice of technology is then, as indicated above, *more* a question of power relations than representing engineering and science based studies of the appropriateness of a given technology. At the Great Belt for instance, the client’s role consequently was to perform within rather tight, politically given conditions, reducing his opportunities of optimising the technological properties of the project.

Although the political interest are no longer directly deployed during design and production, the inefficiencies of the earlier choices start to materialise in these phases. But the technology management approach performed by the involved actors now typically focus on the adaptation of technology within the boundaries of business and project financial calculations.

Such changes in management focus will basically characterise every level and phase of the project, corresponding to the varying technology conception of the specific actors[4]. An obvious assumption concerning the consequenses of this relationism would probably highlight the counterproductive effects of discontinuities in managemen, and therefore urge a paradigmatic normalisation as discussed in the introduction of this paper. On the other hand from the perspective of the actors at stake their actions are undoubtedly driven by the most pressing logic. Therefore in the following the prime aim is explicitly to search for and to identify the management criteria affecting specific technological phenomena on the Great Belt. Secondly it will be analysed, whether the above suggested conceptual perspective actually exposes the limited rationality at work from a more holistic point of view.

TECHNOLOGY CONCEPTS AND PROJECT PHASES

Construction projects are characterised by rather distinct production phases, which serve as spatial demarcations for decisions and actions of separated organisations and actors. The coherence between the phases is then regulated by mainly contractual relations, governing the flow of services, goods and financial transactions. This system feature is often referred to as an *over the wall* situation in the functional relationship between the different contributors to the production process.

As indicated, it is consequently considered necessary hereafter to treat main phases of a construction project as separated empirical fields for technology concepts to materialise - illustrated in the Great Belt case for instance by three periodic cuts:

- the public decision phase: running until parliamentary authorisation.

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[3] This will be demonstrated in detail hereafter, but has also more generally been dealt with by the Groupe Bagnolet in the case studies under the public policy theme - see for instance Working Papers 11 and 14.
[4] Technology conceptions based on for instance theoretical paradigms as listed in Table 1.

- the design, tender and contract phase: progressing from the establishment of a client institution *Great Belt A/S* until the project has been conceptualised and tendered
- the production phase: during which the separate project parts are physically executed

This decomposition might be defined and structured otherwise. In this context, however, it appears reliable as it is roughly backed up by the legal and functional borderlines of the *contracting system*[5].

If furthermore this three-piece project structure is characterised by decision scope and actor type it can then be related to the technology conception scheme. Considering the field of validity of the different theories a parallel proposal for the analytical approach could tentatively comprise of

- *new technology sociology*, in particular the *SCOT* theory (: social construction of technology) regarding the shaping of technological artifacts as resulting from power excerted by social groups' alliances, for instance about major public technology decisions.
- *industrial economics theory*, with the firm's perspective on technology as parameter of competitiveness for achieving strategic goals (contracts).
- *innovation economics theory*, focusing for instance on development of technological capability through learning in firms and production networks.
- *industrial sociology*, introducing for instance a concept of the social constitution of an organisation, which accentuates the coherences in the social system and the integration of formal and informal elements in technology decisions.

This merging of theoretical elements with empirical structures will hereafter be taken a step further in the analytical handling of the two first project levels, whereas the third level is only shortly indicated. As the prime aim is demonstrating a methodological approach it has been necessary to limit the detailing to a minimum and to simplify conceptual frameworks considerably.

PHASE 1 - THE SOCIAL CONSTRUCTION OF A FIXED LINK

Theories regarding technology as socially constructed basically see technological development as arising from negotiations between different social actors, organised in *relevant social groups*, each having their own comprehension of the problems to be solved and the solutions available[6]. Contrary to the linear projection of traditional technology models, this comprehension is multidimensional, making it possible to consider the development of an artifact as an alternation between *variation* and *selection*. What constitutes a *relevant social group* in the SCOT theory is that its members share the same opinion of a given technological solution (the artifact). In an analysis of a technology decision process <u>all</u> relevant social groups must be identified, not on the basis of a priori distinctions between for instance technicians and economists, but - as mentioned - from the shared interests of group members and from an explanation of political and economical power relations between the groups.

In order to understand a technology decision it is necessary to expose the problems and complementary solutions associated with a specific technological artifact by each individual group. A problem is only real if a social group define it as such:

> *Artifacts are ... described through the eyes of the members of relevant social groups. The interactions within and among relevant social groups constitute the different artifacts, some of which may be hidden within the same «thing». In that case, the «interpretative flexibility» of that «thing» is revealed by tracing the different meanings attributed to it by the various different relevant social groups*.(Bijker 1995, p 252)

Thus the interpretative flexibility can be demonstrated by a deconstruction of a specific artifact into several artifacts, which separately are connected to the interpretation of the individual social group. This flexibility exists until consensus concerning the meaning of an artifact

[5] The various national systems are reviewed in a series of contracting system papers by the Groupe Bagnolet - see Working Papers 6 through to 10.

[6] These theories fall into at least three categories (see for instance Bijker 1995): the system-oriented approach, represented by T.P.Hughes, the actor-network approach represented by Callon, Latour and J.Law, and the social construction approach, represented by W.E Bijker and T.Pinch. In the following will only be referred to the last of these.

between different groups occurs. The pluralism of artifacts then disappears in a *closure* (Hansen 1993).

The nature of closure, however, can vary depending on its type and basis of *stabilisation*. If based on strong power it may be a pure rhetorical closure. Or it may be achieved through a redefinition of the technology problem, which opens for new interpretations and consensus between groups.

A concept of central importance in SCOT is the *technological frame*. It originates in predominant practise, theories, tactics, goals and means shared by the group in relation to a technology. Thus it defines the scope of a social group's actions. From this it appears that a technological frame also indicates, how existing technology has a structuring impact on the social environment. However, this structuring of the interaction between members of a group is relative, as it is affected by the members' different degrees of *inclusion* in the frame. A high degree of inclusion will significantly reduce the dynamics in the group. By a low inclusion the group members may even be part of more than one frame.

In the Great Belt fixed link decision process an obvious major methodological challenge is to handle the vast multiplicity of potential relevant groups over an extended time span. A way out is to operate with groups of *central actors* and to analyse in *snapshots* - at given historical moments, when certain changes is known to have occurred[7].

The first snapshot, described below, illustrates the situation in the early 1980s. At that time the artifact was a change of technology in order to secure future transport across the Great Belt. The central actors could be structured in the following relevant social groups:

- THE SOCIAL DEMOCRATS: characterized by a technology frame deeply rooted in a political understanding of the state's active role in society; officially pro public transport technology. Furthermore, in the light of two oil crisis, growth in private car trafic had to be impeded. This attitude was supported by the dawning environmental consciousness. A prime aspect of a fixed link was the positive employment effects linked to construction activities and regional spin-off development. A minor concern, however, was lying in the reduced local employment due to a close down of the ferries. At that time a sole railway connection would have been a solution to the problem. Alternatively a car-railway (shuttle) concept would also have been acceptable. A solution to environmental problems pointed towards a tunnel.
- THE LIBERALS AND THE CONSERVATIVES: political parties, whose frame are closely defined by liberal ideas. Technological solutions based on the public provision of transport were in principal unthinkable. This group defined the problem as protecting the liberty of the individual through establishing a possibility of private car traffic across the Belt. This went well along with an old wish of breaking the Danish State Railways' (DSB) very lucrative ferry monopoly. Although the Liberal Party had concerns about the national economy this worry was suppressed in order to secure solidarity in the group, which accentuated the sole car traffic link as a solution, or alternatively a combined car/railway link.
- THE ROAD DIRECTORATE: coming up to a frame defined by its institutional role as provider of optimum conditions for car traffic. The directorate was always competing with the State Railways for public grants and therefore saw the problem as guaranteeing a car traffic crossing and breaking the State Railways' monopoly. Thus, a best solution would be constituted by a sole car traffic link, and if not possible by a combined link.
- THE DANISH STATE RAILWAYS: also acting within an institutionally defined frame, but in this case affected by commercial interests because the car ferries are representing a substantial source of revenue which should be replaced. A link, which offered priority to car traffic would of course threaten the train traffic; on the contrary a sole railway link would improve the competitiveness of trains. Alternatively a car-railway (shuttle) link would prevent road traffic from exploiting too large benefits. Besides, this might even be good business for the State Railways.
- THE ENVIRONMENTALISTS: a quite heterogeneous group, bound together by a commitment to the protection of the environment. Numerous problems were identified: water flow to the Baltic Sea, spawning locations, the frogs on the island of Sprogø the

[7] As shown by Hansen, E. et al (1995), (undergraduate report, Technical University of Denmark)

general growth in car traffic as a result of a more convenient crossing. Not all members of the group share all concerns. One solution was continued ferryboat transport. However, if impossible to stop the fixed link, a tunnel was preferable.

- THE FIXED LINK OPPONENTS: also a heterogeneous group, having some ideas in common with the environmentalists, but defined within a frame, which consider a fixed link as a token of an undesirable trend in society. The group's solution is total cancellation of a fixed link.

These relevant social groups, their notion of the problem and solutions are summarised in Figure 1.

The second snapshot is taken in 1986, when the Paliament came to an agreement concerning the construction of the fixed link. At this point a merging of several relevant social groups has occurred. The central group now consists of the SOCIAL DEMOCRATS, the LIBERALS/CONSERVATIVES, the ROAD DIRECTORATE and the DANISH STATE RAILWAYS. This group is established on the basis of a redefination of the artifact - from the comprehensive idea of new transport technology across the belt towards what can be characterized as *the balanced fixed link*.

The actors in the group share an understanding of the necessity to balance a solution, which takes into consideration problems like environment, advantages for railways, convenient crossing for cars[8], employment and potentialities for public transport. This solution is called the *time-lagged combined link*.

The group of OPPONENTS still exists, however, now including part of the ENVIRONMENTALISTS group, while the rest of this has been included in the above described agreement. Thus the heterogeneous group of OPPONENTS still associate numerous problems with the fixed link, and they continosly see ferry transport as the only solution.

In this way the redefinition of the artifact towards the *balanced fixed link* resulted in two relevant social groups with significant power differences, finally making it possible for the bridge adherents to make a *rhetorical closure*. It should, however, be noted that for instance the SOCIAL DEMOCRATS apparently considered rejecting the car link at a later point; if correct this indicates a rather low level of *stabilisation* and correspondingly that the *inclusion* of the SOCIAL DEMOCRATS within the frame was low. The situation at the snapshot 2 point is indicated in Figure 2.

In the first snapshot several relevant social groups try to optain dominance - technology is in a *third development stage* (Bijker 1984, p 182), where rhetorics work as the main selection mechanism. No single group achieves full control, but the redefined compromise in snapshot 2 indicates a shift towards a *second development stage*, where one group was dominant. Theoretically, in such a situation a conventional solution was to be expected. Whether the time-lagged, combined link represents conventionality can be discussed; it might, however, be stated that the disclaimer of responsibility for the fixed link's final elaboration (design) points towards familiar technology.

SOCIAL CONSTRUCTION AS TECHNOLOGY MANAGEMENT

As earlier indicated, SCOT theories till now have primarily been applied as analytical tools in research concerned with historical developments in technology. As a basis for an action-oriented concept they must be further elaborated, which indeed is also an evident perspective and ongoing endeavour.

However, in a reflection on the dynamics between snapshot 1 and 2 technology management could be claimed to take place in the merging of the different technology frames through the redefinition of the problem to a dominating frame. The technology manager is an actor (in a relevant social group), who undertakes the assignment of achieving closure of the problem, for instance through entering alliances and agreements which comply with his demands on technology development. Obviously, a necessary prerequisite for fulfilling this task must have

[8] Elements in the agreement were for instance also construction of regional motorways in Jutland in order to provide for regional development.

been an analysis of the actors at work, their mutual power positions and their technological frames.

PHASE 2 - COMPETITIVENESS, TECHNOLOGY AND CONTRACTING

Although representatives of the construction industry are well-known for exerting influence through lobbying on the public decision level in order to generally encourage construction activity and large projects, it is also characteristic that individual firms traditionally are displaying a wait-and-see policy in relation to the technological considerations of a client[9]. Subsequently the idea of improving firms' competitiveness through strategically based investments in new technology is only rarely performed full scale in construction.

During the last decade, however, technology has indeed been put on the agenda as a central object of action in firms and industries. One of the most important exponents of this development is the industrial economist *Michael E. Porter* who elaborated the concept of competitiveness precisely in the relationship between technological change and market conditions. He considers the ability of adapting to new technology to be a significant parameter of success in the mutual competition of firms and industries. But Porter also emphasises the importance of analysing thoroughly the properties of a technology in relation to its market context. Technology in itself, uncritically implemented, very often implies economical disasters (Porter 1985).

As a means of surveying the firm's competitive situation Porter introduced a methodology which has become quite widespread in industrial planning. In a *five forces* analysis a firm can gain insight into the industry structure of which it is part and thereby learn about the conditions that rules competition in a specific market. This knowledge then should determine the technology strategy of the firm.

In order to illustrate the system of sources leading to competitive advantage in the firm, Porter furthermore introduced the concept of a *value chain* - a structuring of the different categories of activities which should be organised and managed specifically with regards to the nature of the different industries. Technology development is one such category which, appropriately handled contributes to the production of value in the firm (Porter 1985, p 260)[10]. The five forces are briefly examined in the following and related to the technology oriented strategic considerations of the contractors in the contract phase.

STRATEGY FOR A BORED TUNNEL

In the Paliament decision about the *balanced fixed link* a railway tunnel represented one of the crucial main elements. In 1987 after the client organisation had been established, tender projects for both an immersed and a bored tunnel were designed by a Danish-Anglo-American consultants joint venture. As furthermore the immersed tunnel could be either concrete or steel based, three technological alternatives were open for bidding.

At this stage the competitive conditions for contractors have already been radically influenced by the client who, in proper conformity with EU rules, had implemented a prequalification procedure and selected four international consortia for the tender. During this process the largest Danish contractors had become included in all four consortia, in fact strongly urged by the client.

Subsequently, these consortia submitted bids for all three types of tunnel solutions, and the client could eventually on this basis decide on the boring technology, referring to the following criteria of competitiveness:

- financially competitive with immersed tunnels
- diffusion of new technology to Denmark

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[9] This attitude is partly motivated in the fact that construction historically seen was driven by order intake. Also the influence of national regulations are affecting construction firms' proximity to market, see for instance Working Paper 9.

[10] Porter's methodology has played a significant role in several recent surveys concerned with future development of the Danish construction industry. Not least the value chain model has focussed attention on the problem of managing technology development under the fragmented organisational conditions in construction. The industrial policy, promoted by for instance the Ministry of Business, is subsequently giving strong support to a strategy of «vertical integration» (see Working Paper 4)

- least impact on the environment

The client, however, also drew attention to the fact that boring technology increases the risk of delays and related financial losses[11], but finally, five months after tender, the parliamentary majority behind the fixed link adopted the recommendation of the client.

If observed from the point of view of a contractor, such as the MT Group, trying to optimise its competitiveness, the five forces of Porter can offer a partial structuring af the situation.

The basic level of competition is in fact quite well-known: *«Threat of New Entrants»* are practically insignificant as the prequalification of four consortia have excluded intrusion from other actors. More real, however, is the *Threat of Substitution* as an overall question as well as concerning the selection of tunnel technology. Undoubtedly MT Group and its rivals face the risk of the total cancellation of the project if they price a bid too far above the client's budget. In that sense the threat of the existing transport technology, maybe even intensified by emerging types of high-speed ferries, leaves no room for contractors to add in large time and price safety margins. Furthermore, the threat of substitution in relation to type of tunnel should be taken into account. As this final selection of technology is awaiting exactly the results of tender, evidently every prequalified consortium will be facing the dilemma between either concentrating its tender efforts on one specific type of tunnelling (which would minimise technological risk but enhance competitive gambling) or submitting bids for tender on all three tunnel types (which would reduce the threat of substitution but be costly and very demanding on technological competence). All four consortia employed the second of these strategies.

Rivalry Among Existing Firms during a tender procedure is primarily aiming at presenting the lowest (qualified) price for the client. For the consortium the critical balance is to hit this price without taking excessive economic risk, i.e. it must underbid the competitors but still be able to execute the project within the contracted budget. Technology, however, constitutes a central momentum of this competitive situation, for instance through modification of mere price calculations:

- the consortium possessing the highest competence in relation to the technology demanded by the client, can manage the production most efficiently and therefore submit the lowest bid for tender
- based on strategic considerations about potential advantages such as achieving technological capability and market access the consortium might choose to downgrade the importance of the specific project profitability and then lower its bid
- a thorough appraisal of the technology based evaluation of the client's project tender design might reveal weaknesses in the tender conditions, which later during construction will be deliberately used by the consortium as a lever in budget negotiations, claims and arbitrations. The initial bid can therefore be lowered.

Obviously, a consortium's possibility of employing such rationally substantiated technology strategies as means of rivalry is severely impeded by the sheer complexity of the project and tender procedure itself. Their exact conversion into a calculated price bid is therefore extremely risky - hence the quite common assertion that the contractor who miscalculates the lowest price wins the contract! (Bonke 1995).

Also the Porter force *Bargaining Power of Buyers*, plays a crucial role for the free scope of technology management. The Great Belt A/S, being in this case a professional buyer with well-developed ideas about the feasibility of technological solutions and subsequently setting quite detailed terms for their realisation, evidently is able to maintain tight restrictions on the manoeuvrability of the consortium. Again this is a difficult act of balance for a consortium which is determined to win a contract on the fixed link: how far should it follow a client's specifications and conditions at the expenses of its own business and management experience? Undoubtedly, the traditional attitude of one-off order production contractors is quite indulgent towards a client and consequently underestimating the importance of constructability.

The consortia must finally also take into consideration the *Bargaining Power of Suppliers* in their estimations of technological competitiveness. Compared to ordinary building projects the tunnel

[11] News from Storebælt No. 7/88, p 2

project leaves only a little room for the contractor to exploit business strategies towards suppliers. At least two causes of this constraint can be identified:

- from the very beginning of the public debate about the fixed link project the argument for domestic multiplier-effects was given high political priority. Formally as well as informally this was passed on to the client as an imperative, obliging construction consortia to bring themselves in a rather restricting state of dependence on the relatively few potential Danish suppliers (and subcontractors)[12].
- in particular the bored tunnel project appeared to involve problematic supplier aspects, due to the client's detailed provisos concerning the number of boring machines, their technological properties and the terms of their delivery. Only one international supplier appeared capable of complying with these demands, leading to a contractual relationship which soon caused severe technical and economic problems (Bonke 1996).

MANAGING TECHNOLOGY FOR COMPETITIVENESS

In order to improve the firm's competitiveness during the design and contract phase a technology management task must in particular focus on the technological demands inherent in the specific project in relation to the firm's competence. In case of large complicated projects the formation of international consortia should consider not only financial requirements but of course the intention to upgrade this technological competance.

Furthermore technology management adapted to this project stage is about analysing the surroundings of the project and reacting to these. A contractor which on the basis of thorough investigation has identified its position and competitive advantages in relation to the rivals, can utilise this knowledge for differentiation and access to the client. But this approach is also a necessary requisite for qualifying decisions to withdraw from projects, (which, indeed, some contract winners at the Great Belt must regret not to have done).

CONCLUDING REMARKS

Two project stages have been briefly analysed above, applying different theoretically based technology concepts to empirical circumstances observed at the Great Belt Fixed Link. As indicated on page above, this methodology can be expanded to succeeding project stages.

Thus in *innovation economics theory* can be identified concepts relevant to the structuring of firm's handling of technology during production/construction. For instance Schumpeter's notion of technological innovation in relation to the behavioural patterns of two basic manager profiles, with the classical «entrepreneur's» innovative drive under high uncertainty as very characteristic for construction[13].

Bessant (1993) furthermore concludes that efficient technology management in production depends on profound comprehension of technology itself and of all its aspects. Poor management in the process of technological change, for instance concerning the organisational adaptation to a specific technology is a basic problem, frequently observed also at the Great Belt. Bessant recommends continuous investigations, eventually leading to the «learning organisation», as important provisions.

Also theories of *industrial sociology* contributes to the understanding of technology implementation on firm level. Under the concept of «social constitution» are defined central policies, rules and norms influencing employees' behaviour, motivation and productivity (Clausen & Olsén 1994). The cultural divergencies of these are of course a central aspect, generally urgent in the temporary organisations of construction and in particular evident in the international consortia at the Great Belt.

However fragmented this analytical approach appears at this level of conceptualisation, it does provide an initial insight into the chaotic driving forces of a large construction project. In this way it represents an almost symbolic interpretation of the atomised construction process, during

[12] Some of the main legal, economic and productive consequenses of the socalled «buy Danish clause» have been described in Working Paper 14.
[13] See for instance Pavitt(1990)

which a multiplicity of independent actors and interest deploy their planning and management paradigms.

Technology management is becoming increasingly urgent with the growing complexity of projects. Knowledge about properties and demands of specific technologies are equally important on high and low levels in project organisations and in firms, and must be operationalised if project success and competitiveness is to be achieved. An elaborated methodology seeking to refine the coordination of different management views and their corresponding disciplines such as indicated above, can hopefully contribute to this strategy.