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THE DEVELOPMENT OF CORPORATE SOCIAL CAPITAL IN COMPLEX INNOVATION PROCESSES

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From 1990 to 1995, a core group of engineers in Norway's APL (Advanced Production Loading) and Framo Engineering, with the support of Statoil, developed two complex technologies for floating offtake and oil production in the offshore oil industry. The project ultimately involved 113 participants spanning 32 organizations. This paper asks why did the ideas of these technologies emerge at that time and among these people? Why were they developed so efficiently? We investigate the role of Corporate Social Capital and the social network position of the initiators of the innovations. We study the coordination of knowledge and the mobilization of complementary resources required to develop the technologies.

The subject technologies, STL/STP (Submerged Turret Loading/Submerged Turret Production), are systems for offshore, marine vessel located buoy loading, and multiphase pumping and oil production from underwater installations. (See http://www.apl.no/ for details of the technologies). STL is a submerged and anchored cone shaped buoy. Tankers, which have been fitted with a cone shaped intake for the buoy in its bow, can connect the buoy to the vessel. The design and operation of complex technologies like these require knowledge from several disciplines. Experts from different fields and organizations cooperate to design, develop, build, test, and conduct installations and field testing of the technologies. Then they verify the simulation models during field operations. In a project of this scale, disciplinary boundaries reach across fields so diverse that engineers from one discipline often cannot master the other disciplines on which the technology is based. No single individual completely understands the whole system. To succeed, they draw on informal social networks to coordinate and mobilize resources across several firms and disciplinary boundaries. This is referred to as using social capital.

This paper demonstrates how social capital contributes to innovations. Social network position is crucial in generating ideas and in coordinating expert knowledge in social networks. The social system that comprises the work setting of engineers plays an important role in the mobilization of participants in innovations. We show how resources may best be mobilized in a network and not a firm, especially in innovations that demand new assets. Further, since complex innovations demand unforeseen resources, these are often mobilized through informal social networks.

Our theoretical discussion first summarizes prior research on mobilizing resources for innovations, which have traditionally stressed formal strategic alliances. In contrast, our contribution is on the role of informal relations in project development, and we turn to an analysis of this social structure. We note that specialists from diverse disciplines communicate through shared frames of reference and an understanding of how other fields can contribute to complex innovations. Social structure must support this communication for a complex project's success. We follow with an analysis of the social network of 113 engineers in 32 firms, drawing on network data spanning the years 1991 to 1995. The network analysis uses block models of the social network. The results of the block model analysis revealed four main task areas, reflecting different fields of expertise. The analysis shows the early origins of these blocks have implications for the actors' ability to generate the social capital they use for the projects.

MOBILIZING RESOURCES IN INTERORGANIZATIONAL RELATIONS

Researchers commonly assume that most innovations are performed within one firm. Firms need to structure innovative activities by formally combining personnel that can produce successful innovations with existing in-house manufacturing resources (Nonaka, 1990). Most of these studies on collaboration remain at the level of formal commitments, revealing that the development of complex innovations requires a heterogeneous mix of assets (competence, capital, and physical assets) at different levels of the value chain, which can be defined as a network of supplier and customer relations.

However, some studies of complex technologies find that external collaborators figure in the innovation process as technology users (von Hippel, 1988). In biotechnological research, small specialized firms collaborate in strategic alliances with larger firms (Arora & Gambardella, 1990, 1994; Powell, Koput, & Smith-Doerr, 1996). Professionals in Silicon Valley also draw on their informal networks to collaborate (Rogers & Larsen, 1984; Saxenian, 1994).

Studies of strategic alliances reveal several ways that firms tackle the needs for mobilizing other firms' resources for project innovation. Called complementary resources, these are assets external to any one firm that are necessary to accomplish an innovation or to complete a task

(Teece, 1987). Since advanced technologies require a complex set of resources that may not be present in any single organization, firms may use other firms' resources. These assets include their technologies, information, and organization to combine and coordinate expertise.

Complementary assets can be mobilized through strategic alliances, but they may not be sufficient or the right kind. Innovations often require a new set of resources not employed in the current production. Moreover, innovations require openness, willingness to take risks, and trust, which is only built up over years of informal interactions between people in the firms (Axelrod, 1984; Krackhardt, 1992; Oliver, 1997; von Hippel, 1988). However, strategic alliances are formally governed by economic incentives and bureaucratic systems. Consequently, Kotabe, and Swan (1995) find cooperation between firms operating at the same level in the value chain rarely promotes innovativeness.

Even in formal alliances, there is evidence that organizational properties may have an impact on external relationships. The diffusion of common norms and values between Japanese firms facilitate interfirm exchange. These organizations deliberately use personal networks to reinforce exchange and reduce coordination costs (Yoshino & Lifson, 1986). Indeed, personal relations ease these problems in governing interorganizational relations between firms (Kraut et al., 1999).

Strategic alliances and personal relations are not alternatives. Some strategic alliances evolve from personal relations. Benassi (1990) found that personal relationships and past experiences among key actors were critical in the start-up and negotiation stages. In the implementation stage of innovations, partners have to develop a mutual understanding, solve possible bottlenecks, and fine-tune their decision-making. From this perspective, alliances can be seen as evolutionary, complex social systems (Badaracco, 1991; Benassi and Bhargava, 1990; Lewis, 1990; Lorange, Roos, & Bronn, 1992). They cannot be reduced to a simple matter of planning and finding ex ante strategic complementarity. Trust and mutual solidarity may help establish and maintain interorganizational relations (Gherardi & Masiero, 1990; Krackhardt, 1992; Oliver, 1997; Staber, 1994; van de Meer & Calori, 1989). Social networks may either benefit or impede knowledge transfer in interorganizational networks (Groenewegen, 1992; Swan, Newell, & Robertson, 1995).

Social systems are useful to gain access to complementary resources. Some resources that are required may not be available in a market or may be hard to define as existing resources

because they are created through interaction. Intellectual resources are a key component of technological innovation. Firms and individuals that participate in professional communities partly share and partly use distributed knowledge (Powell et al., 1996). To access these resources during innovation processes, firms establish formal interorganizational relations, using internal knowledge to draw on external information (Arora & Gambardella, 1990, 1994). Experts use their social networks for technical discussions and problem solving, and this creates new knowledge (Nonaka, 1991). Thus, even studies of formal interfirm alliances find evidence of social structure.

Social capital

Technical innovations need particular kinds of social capital. They create products or processes by recombining existing resources and introducing new ones. Where an innovation is highly complex and involves a radical departure from earlier processes, new specialties and often more people may be involved. The glue is social capital. To understand this process in general terms, we need to introduce several features of social capital that aid innovation.

We define a firm's ability to develop or adopt innovations as its absorptive capacity (Cohen & Levinthal, 1990). Absorptive capacity refers to a firm's ability to perceive opportunities and use external information to develop profitable products or production processes. Organizations have both formal and informal structures. To reach external information sources organizations can use their formal relations, or they can depend on personal relations of their employees (Knoke, 1999). In contrast to those studies that focus on the formal ties, we find that social capital is embedded in social structures as relations that can enhance absorptive capacity.

Social capital is part of a social structure that is embedded in personal and organizational contacts. The informal structures are the connections among people covering both work and nonwork related interactions. Informal relations may also extend across organizations, such as professional networks, friends, and colleagues from earlier jobs. Social capital is the set of resources, tangible or virtual, that accrue to actors through social structure, facilitating the attainment of the goals of the actors (Gabbay & Leenders, 1999).

The set of people with whom an individual communicates is the direct social capital of that person (Bourdieu, 1986; Burt, 1992; Coleman, 1988). A person may have active or passive relations with these people. Passive relations refer to former contacts, which, in contrast to active rela-

tions, are not currently used, but they may be mobilized for new activities. Social capital represents the competence of their network contacts, which is influenced by their interactions with other people giving indirect network effects on the direct social capital. We use the term social capital because it is not a sole property of any one individual but is shared among several people. However, social capital also connects individuals to a set of expectations, obligations, and social norms that govern behavior in social systems (Bourdieu, 1986; Coleman, 1988). In this way social structure may have liabilities as well as social capital (Gabbay & Leenders, 1999).

Organizations are part of value chains, or a network of supplier and customer relations. Suppliers deliver the inputs that the organizations need. When firms innovate, inputs are new, and they may need new suppliers and new sources of engineering knowledge. The pattern of complementarity changes, and the existing corporate structure is not sufficient. Personal relations may come into play. The actors may explore a set of relations widely to find useful sources of knowledge. Since most actors are part of social structures based on their earlier activities, they do so by mobilizing this set of relations to solve the new problems.

Social structures contain different types of relations, some economic, others professional, and some personal. A social structure may be divided into different layers with some actors who share all relations, or some who only participate in one type of relation (Granovetter, 1985; Scott, 1991). Some relations overlap, and this is referred to as multiplexity. Actors participate in multiplex social networks, activating various parts of the social structure for different problems. For any given problem, some relations may be beneficial and others a liability. Social capital that is beneficial in some phases of a process may not be helpful for later phases (Gabbay & Leenders, 1999). The sequencing and activation of different social relations may determine whether the social structure provides social capital or liability.

Social capital is goal specific, the goals may be both individual and organizational goals. When individual or group goals become organizational goals, the social capital of the individuals or of the group becomes “Corporate Social Capital” (Gabbay & Leenders, 1999). Although, many follow Coleman’s (1988) definition of social capital as an individual property, this limits the use of the concept to an individual level analysis. In fact, certain positions in firms also give people opportunities to build social relations. The firm provides its employees social capital, while individuals also bring their social capital into the firm, thus augmenting the social capital of both

(Gabbay & Leenders, 1999). This permits us to study relations among individuals representing firms, and relating Corporate Social Capital to a firm's output,

The position of a firm in a network of firms (its "centrality") affects the quality of and its ability to access and use Corporate Social Capital. A central position offers better access to social capital. Firms that are central in collaboration networks, have a higher output of patents than less central firms (Powell, Koput, Smith-Doerr, & Owen-Smith, 1999). Our summary of the existing literature suggests that one way to explore Corporate Social Capital is to focus on complex inter-firm innovations.

Knowledge, cognition, and communication in social networks

The innovations we study are radical, with new components and new architecture. By architecture is meant the way components are fit together to make the devices work. Architectural changes imply a change in the perception of causal relations and are most difficult to adopt (Henderson & Clark, 1990). A large number of individuals from many disciplines and subdisciplines contributed to the successful outcome of this innovation. Their ability to combine their knowledge was no mean feat.

Most technologies evolve over time through step-wise improvements. Users establish a common paradigm for how specific tasks should be handled. Firms take the technology for granted, and often search for solutions to problems within the paradigm by incremental changes of the technology (Vaughan, 1996). However, commitment to a paradigm may be problematic for two reasons. First, some technologies run into problems either during testing or in operation. Without cross disciplinary exposure, engineers would accept core technologies and they would not challenge these paradigms. If problems cannot be solved within the paradigm, engineers would not know whom to ask for new resources. Nor would they know how to communicate with those other fields (Pinkus, Shuman, Hummon, & Wolfe, 1997). Failures often occur because actors lack knowledge, or they do not include people with the required expertise in problem solving (Weick & Roberts, 1993). Without cross disciplinary exposure the engineers may not even recognize what causes a problem (Pinkus et al., 1997; Vaughan, 1996). For instance, conformity to a ruling paradigm is the source of technological disasters when engineers are unable to recog-

nize or interpret data that indicate sources of problems (Perrow, 1984; Pinkus et al., 1997; Sagan, 1993; Vaughan, 1996).

In contrast to incremental changes, complex innovations like those we study are only possible by drawing on the expertise of several participants from different fields. Their division of labor is essentially a division of cognitive labor (Hutchins, 1991). Each specialist provides part of the expertise necessary to supply the total knowledge required to solve problems; professionals tend to trust each other because of their common denominators (Oliver, 1997). Because they are outsiders to each others' fields, they can only communicate by developing a shared frame of reference. Shared frames of reference develop when participants perceive and interpret information in similar ways, are able to solve problems, and develop a common repertoire of communication practices (Orlikowski & Yates, 1994). They can communicate because they share knowledge and understanding of the topic. Based on a shared frame of reference, experts deploy their expertise to solve specific problems allowing a joint solution to be made by all participants. They do not necessarily have to understand the expertise of their collaborators. They do need to know how their diverse contributions can facilitate a joint solution. Therefore we need to investigate the following conjecture:

Research area 1: To communicate effectively within a profession requires social networks that have evolved over a long time, creating clusters of specialists that solve joint problems. This is the creation of social capital.

People share information and interpretation by communicating and are influenced by each other as a consequence of their position in the social network (Friedkin and Johnsen, 1997). Interaction is structured and social network position determines each individual's access to information and to other actors in the network (Friedkin and Cook, 1990). Social positions are associated with the actors' different cognitive representations, or what they know and how they use their knowledge (Pattison, 1994). Communicating within one technological paradigm shapes the social networks of engineers using a specific technology, creating technology specific network clusters. People who interact frequently tend to think in the same way, and to trust only the information that comes from a set of known actors (Krackhardt, 1992). This set of actors constitutes their social space and blocks out other information sources. Building a professional network within one field, may obstruct cross disciplinary communications, and thus the social structure may easily

produce a liability. This property of interaction creates a bias against radical innovations, whose novelty challenges accepted thought. Consequently, radical innovations often occur on the fringe of a social system of core actors within an industry (Tushman & Anderson, 1986). The innovations we study are radical bringing together new and standard components with a new architecture. Therefore, we expect the following conjecture to hold:

Research area 2: To develop radical innovations, developers need to be positioned between actors developing new knowledge and potential users in the fringes of core industries.

We shall investigate if the originators of STL/STP have a social network position crossing several functions and levels of the value chain within the North Sea oil industry, bridging organizations developing knowledge and potential users of the technologies.

Research area 3: Radical innovations require cross-disciplinary communications, therefore, we need to analyze the ability of the social network positions of the engineers to coordinate interdependent actors.

This particular social network position is visible through connections between network clusters of specialized fields. Links between clusters enable cross functional coordination and problem solving.

METHODS

Preparation of the study

This descriptive case study uses qualitative and quantitative methods. We gathered information from the informants on the development of the technologies through lengthy discussions. They gave us articles, technical descriptions, and blueprints of the technologies and explained how they worked. This information is essential for being able to successfully interview the project participants.

Before we interviewed the participants we read through all the materials about the innovations. we talked with the developers about technical aspects to understand the technologies. In this way we mastered the language of my respondents and understood what they were referring to.

From the vitae of 23 of the most central people in the development process, we got information on their educational credentials, a chronological list of all the firms they had worked with, and what type of projects they had been involved in. we got social network data of all types of relations that were important in the development process.

Gathering network data through interviews

The name generation took several stages. We distinguished between those central and those marginal to the development process. First, we conducted initial interviews with key people in the development project for STL/STP at APL, Statoil, and Framo Engineering. These informants had a very good overview of the whole network involved in the project. Based on these interviews, we designed a name list of all people who had been involved in the development of the technologies. This was followed by interviews with almost all of the employees at APL and Framo Engineering, and all Statoil employees that were active in the project. We also interviewed some key people in other firms. Because the initial informants were well placed in the network, before long no further names appeared.

After generating a name list from the initial interviews, we mailed it to those we planned to talk with before the interview with a letter explaining the study and the purpose of the name list. During interviews the respondents had the name list in front of them. They talked about each relation giving us their story of how they were related. We also provided empty space for more names, which were used for the next interviews. We also specifically asked for each person on the list how long the respondent had been related, how often they communicated, and the content of the communications. Based on the interviews we divided the contents of the relations into the following classes: 1) technical discussions, which were part of almost all relations, 2) discussions about fabrication, 3) supplier relations, 4) sales of the technologies, 5) other commercial relations, and 6) friendship connections.

The unit of measurement in social network analysis is the dyadic relation. The interviews map all the relations in a network. For this we need not interview everybody in the network. We classify engineers as central or marginal based on attributions by key developers and the number of direct and indirect referrals from others. Those with few referrals we defined as marginal. We first interviewed engineers that our key respondents selected, then snowballed the interviews to

others that had many references. We learned about the relations between the marginal actors by asking the key informants that first mentioned them. We call these relations between marginal actors "attributed relations." Generally, two or more respondents confirmed an attributed relation. The data matrix has 919 relations, of which only 41 are attributed relations. This method, called "capture-recapture," is useful for getting network data from some of the people in large networks (Burt & Ronchi, 1994).

To understand how networks change over time, we asked respondents how long they had been interacting. We distinguish two different networks in our analysis. First, relations between engineers before STL (before 1990): these connections evolve into a cross disciplinary professional network. The earlier networks include relations that later became active in technology development and commercialization. Second, to analyze structural changes during the project period, we generated yearly network matrices for the development of STL/STP between 1991-1995.

Network measures

We analyze the relations between participants who exchange technical information about the project. We use 5 indicators of centrality to measure actor position and network properties. Degree, which measures the number of direct contacts for any actor, represents the total number of information sources. Closeness centrality, which measures the reciprocal distance to all other actors in the network (Freeman, 1979), illustrates connectivity to the rest of the network. Betweenness centrality is computed as the number of optimal paths passing through each node in the network. People located between clusters have high betweenness centrality, which means that they can control information flows and act as brokers. This measure also indicates hierarchy in a network. Flow betweenness centrality has an advantage over Betweenness centrality. By computing all information paths in a network and not only the optimal paths (see also Wasserman & Faust 1994), we learn how actors may bypass busy nodes and avoid their constraints or liabilities. Information centrality is determined by the total flow of information between any two actors in the network, using all paths; information loss is calculated on the number of nodes connecting them (Stephenson & Zelen, 1989).

All networks have some form of clustering. Network density is a measure of how many relations (*l*) among n people exist compared to the maximum possible number of relations: *l*/[n(n-1)/2]. Structural equivalence partitions the network into groups of actors with similar network positions. We use the CONCOR method (CONvergence of iterated CORrelations) for dividing the network into 4 groups (Borgatti, Everett, & Freeman, 1994; Breiger, Boorman, & Arabie, 1975; Wasserman & Faust, 1994), which are the basis of block models. The reduced image matrices display network densities within and between blocks (Wasserman & Faust 1994). The evolution of the communication networks over time is reflected in changes in the block structure.

Structurally equivalent actors have a social position sharing communication sources and tasks. Structural equivalence can be used to define an economic or ecological niche (Burt & Talmud 1993). A niche consists of structurally equivalent actors having similar input-output relations, this is equivalent to flows in value chains. The block matrices display the densities of relations, and hence the dependencies of actors within and between blocks.

RESULTS

The Development of STL/STP

Several firms and research institutes in Norway are active in basic research and technology development for the offshore oil industry. Although most of the firms are small, their employees participate in professional social networks that span several organizations. The small size of many firms, in a country whose professional elites tend to come from the same universities, prove a good site for this case study on the contribution of social networks for radically new technologies.

The innovations we study, STL/STP, are revolutionary. They became possible after fundamental breakthroughs in basic research and the development of the rotating connector technology. In the late 1980s and early 90s researchers at Marintek and SINTEF (a research organization at NTNU (The Norwegian University of Science and Technology) made a breakthrough developing a simulation model for anchoring systems to assist floating production and loading. Simultaneously and independently, Framo Engineering developed a rotating connector for flexible pipes for pumping oil under high pressure. These two innovations prepared the technological ground for a buoy system that anchors both itself and the ship during offtake of oil. The rotating connector

makes it possible for the ship to turn according to the wind without twisting the risers (flexible pipelines). With this system, the vessel always faces the wind and waves, enabling loading in even the highest waves of the North Sea, while they pump oil under high pressure without spills. These twin innovations provide good examples for tracing the contribution of social networks, since their onset and development occurred in such a narrow time span and the contributors can be well documented.

STL development. The pipeline is the conventional method of transporting oil from a production site. In the North Sea, some companies began to use buoy loading onto tankers while planning a pipeline. They developed better technology and routines for loading oil using buoys and decided to cancel the pipeline despite investing millions in several years of preparations. However, conventional buoys have some difficulties mooring and operating oil tankers in high waves. When wind direction changes, vessels turn around and may twist connectors and pipes. In addition, there are no standards for connecting oil pipes to tankers.

During 1990 and 1991 Arne Smedal and some of his colleagues at MCG (Maritime Consulting Group), developed a new buoy loading concept (Smedal and Bergmo, not dated). Kåre Syversen was a key player. Engineers from Statoil and one now employed at DNVC (Det Norske Veritas Classification) participated in the early development. A prototype of STL was produced during 1992.

MCG and Statoil founded the firm APL early in 1993. Some of the personnel from MCG moved to APL to design and prepare STL for oil field installations. Field installations started in 1993/1994. The oil fields have a main operator, BP or Statoil [1]. In the Norwegian part of the North Sea other companies participate together with Statoil. This gives them an opportunity to observe and gain experience with the new technologies.

During the development of the STL system, the developers drew on other firms and research institutions, which contributed computer programs for simulations of operations, strength of materials, connections, and metallurgical analysis. Most of the APL employees were educated at NTNU. Kåre Syversen was a NTNU faculty member before joining MCG and, later, APL. His former students participated in the project. The developers had work-related contacts made through other projects in the North Sea. As the engineers worked in different firms during their careers, they forged yet other ties. It is common in the oil industry in Norway for people to have

their physical work place at another firm's office than where they are employed, which increases their career mobility, and it creates many useful contacts for future work.

As a consequence of their careers and their social networks, these innovators were positioned between organizations doing basic research in technology relevant to buoy loading and users of buoy technologies. Therefore, they were familiar with the problems of conventional buoy systems. The close connection between Arne Smedal and Kåre Syversen to Marintek, Statoil, and Framo Engineering, combined with the problems they were working with at MCG, created the setting for developing the concept for STL. When anchoring models and the rotating connector technology were developed, two of the main pieces of knowledge were available. The rotating connector had been tested and verified. The anchoring technology had been developed as a simulation model. Marintek in Trondheim also performed experiments in a model tank. Final verification of this model took place at oil fields. Since each installation is different because of sea bed geology, sea depth, currents, winds, waves, and largest wave specifications, each field has to be designed, pretested (simulations), and verified. The connections the developers had to Statoil and BP made the first field installations feasible. Each installation is costly, but the oil firms were convinced by their networks to take the risk. The payoff would be considerable. So far, 5 years of reliable production and verifications have supported the models.

STP development. At the same time as STL was developed, multiphase oil production was invented by researchers in a group of firms and research institutes. By maintaining oil well pressure, the process more than doubles the yield of an oil field [2]. The STP unit is a multiphase oil production unit that can be built into a tanker. It is built on an STL buoy that extracts crude oil from the well head and transfers it to the tanker. This eliminates the need for an oil production platform. Since the unit is located in a ship, it can be used at several fields, which makes possible extracting oil from small fields. Martin Sigmundstad in Statoil got the idea for the STP system. He had been managing director of Framo Engineering from 1983 to 1991, and had been working on STL since then in Statoil. He had a good understanding of Framo Engineering's capabilities and products, he also was one of the oldest in the network.

The social networks of the initiators of STL/STP spanned all the firms and R&D institutes where basic knowledge was developed. The engineers were also connected to different types of expertise needed for the development and operation of an oil field. Several firms participate with

their specialized knowledge. These firms have experts in geology (including oil and sea bed geology), pipe-lines, pumping, platform construction and running, energy producers, and suppliers of all kinds of equipment. Another set of experts are needed for pumping, production, storage, transferring oil to tankers, and safety issues for offtake of oil. The last set of experts, shipowners and marine operators, handle loading, storage, and transportation of oil.

The innovations were completed within a social structure that contained rich social capital. However, since social structures are layered in a multiplex set of relations, some structures may be a liability and could have endangered the project (Gabbay & Leenders, 1999). Looking at the relations we note the absence of top level management. This is because the project was largely run by the engineers; they obtained budgets and permissions to go ahead after they had started the development. They did not seek approval before they could demonstrate that the project was feasible. In this manner, loose coupling of relations in a network of small interconnected units avoids liabilities of the social structure. If there had been tighter coupling, the probability of doing this project would have been much lower.

The marginal position of the developers in relation to the big oil companies also held the liabilities of social structures in check. Statoil is a newly founded oil company, which despite its size of approximately 18,000 employees, is dwarfed by other leading global competitors. As such Statoil has no strong norms about appropriate technologies (Henderson & Clark, 1990). As well, Statoil had observed the inefficiencies and defects of the traditional offshore oil technologies that had been developed under far more benign environments than the North Sea.

The innovators had a social network position with direct contacts to organizations that did fundamental research. They also connected directly to users of the technologies. This made it possible to apply new knowledge to radical innovations. Their long careers within the marine-based oil industry endowed them with social capital that spanned all functions across the whole value chain of offshore oil production. The 23 most central engineers have held a mean number of 5.4 jobs (range 2 - 12) in 44 firms and institutions. The mean number of engineers from this network that had worked within each of these firms is 2.3, with a range of 1 - 16. The firms with the highest number of people working for them are: Statoil, APL, Frank Mohn, Framo Engineering, Shell, and Norsk Hydro. Twenty-one of the 44 firms who had employed one or more of these people later became involved in the development of STL/STP. This demonstrates how the engineers built

their social capital during their careers, and how they became part of the Corporate Social Capital of firms they had left.

Analysis: The development of the network

We analyze two sets of networks, the first is the development of the relations that later became active in the innovations, to attend to research questions 1 and 2. The second is the evolution of the network during the projects themselves, which is related to research question 3. The data on interpersonal relations date from 1963. Our analysis of networks formed during project work spans 1991 to 1995.

The network was founded first on trust developed during long periods of interaction (Krackhardt, 1992). Belonging to a professional community, whose members knew how to communicate, they exchanged technical information and solved problems, increasingly sharing frames of references. Since most worked in different organizations, they became adept at coordinating diverse knowledge to solve problems. During this time, the complementary knowledge that would prove useful for innovating STL/STP formed.

The amount of available knowledge resources can be seen in the growth of the network. The oldest relations were established by the mid-1960s. Then the network grew as new engineers began to work together and later enter the projects. The size of the network increased rapidly to: 1985, 35 participants; 1990, 57; 1994, 113; 1995, 108.

The structure of the network changed as engineers joined common activities and were connected to each other. By 1970 one cluster had formed around STL-originators Arne Smedal and Kåre Syversen. Another formed around the STP originator, Martin Sigmundstad of Statoil, formerly of Framo Engineering. In 1985, nearly all (31 of the 34) network participants were connected to each other. The development of the two technologies are also reflected in the network structure. As more people became part of the STL project in 1992, and as STP evolved in 1994, centrality measures undergo changes.

Table 1 shows the changes in the network measures. The most stable property is network density, which remains stable during the observation period. The normalized measures of centrality are comparable across the years. Network degree increases because the most central people add more relations as the network grows, particularly between 1992 and 1994. The total size of

the network and the number of central actors' contacts increase, but the mean number of contacts is stable as new participants with fewer connections are added. This suggests that the new engineers that joined the network are connected to existing groups and did not create their own groups.

We found a comparable result for closeness centrality. As more engineers that previously were unconnected joined the network, the paths between central and peripheral actors shortened. Some engineers with high centrality connected a large number of others to the rest of the network. In the beginning of the observation period, these central people not only had better access to the whole network, they also served as important communication bridges. Later, network betweenness centrality is reduced as more people became connected to each other. The importance of the central figures as bridges was reduced.

Table 1: Measures of centrality, % centralized for the whole network. Means for individual positions

Year:	1991	1992	1993	1994	1995	end 1995
Degree, % centralized	33.2	57.2	71.6	65.9	70.5	69.3
Mean	3.39	4.36	6.24	7.84	8.26	8.19
Mean, normalized	5.84	6.60	6.86	7.13	7.65	7.65
Closeness, % centralized	39.3	51.4	71.5	66.6	69.6	68.5
Mean, normalized	33.6	40.2	45.4	44.6	46.3	46.1
Betweenness, % cnt.	46.6	58.9	63.7	48.4	49.8	48.7
Mean	129	104	111	139	132	132
Mean, normalized	3.89	2.42	1.36	1.16	1.14	1.17
Flow betweenness, %	36.2	35.7	36.5	19.8	20.5	20.2
Mean	116	121	196	280	297	281
Mean, normalized	2.91	2.04	1.29	1.02	1.05	1.03
Information, mean	0.38	0.34	0.82	1.24	1.12	1.11
Network density (alpha)	0.06	0.06	0.07	0.07	0.07	0.07
n	59	67	92	111	109	108

Comparing the betweenness centrality measures with the flow betweenness measures also reveals that early in the period there were fewer alternative paths; more engineers depend on a few core individuals. As development starts, more people become directly connected and network flow betweenness centrality decreases. The network becomes less dependent on those few central people to serve as communication bridges. Some people have high centrality, but there are more alternative information paths and more people are central in the network. This is illustrated by the increase in information centrality.

Structural equivalence blocks, 1991: Buoy design

The concept for STL was conceived in 1991 and a prototype was built in 1992. We used the relations that existed in 1991 to divide the network into four structurally equivalent groups using the CONCOR method [3] (Breiger, Boorman, & Arabie 1975. Table 2 shows the results. The analysis is based on individuals; the table displays firm names and the number of people working within each firm. This reveals how individual relations contribute to Corporate Social Capital.

Table 2: Structural equivalence groups of the network in 1991. The numbers in parenthesis indicate the number of people in each firm (firm name shows employment in 1995)

Block 1	Block 2	Block 3	Block 4
APL (8)	Framo (6)	APL (2)	Statoil (1)
Framo (1)	Statoil (11)	Statoil (5)	DNVC (1)
Statoil (3)	MCG (1)	DNVC (1)	Marintek (1)
Brd. Johnsen (3)	Rasmussen (2)	MCG (1)	Norsk Hydro (2)
DNVC (2)		Stolt Comex Sea-	Scana Staal (1)
MCG (1)		way (2)	
Marintek (2)		Yme (2)	

In 1991 the STL design work progress and the groups of structurally equivalent actors reflect the different niches that were to become essential in developing STL/STP. Block 1 consists of STL developers; Marintek developed the crucial models for designing anchoring systems.

Block 1 contains Arne Smedal, who got the idea for the buoy, and Kåre Syversen, the most central person in the development. APL had not yet been established, and the 8 people from APL in this block worked at MCG at this time. The block also has marine consultants, Brd. Johnsen, manufacturer of parts for the STL buoy, and those from Statoil that supported the development; Statoil is a future user. Framo Engineering (the firm that in 1994 became STP developers) was also part of this block. That the institutions and the firms which developed the knowledge were in the same block, indicates how close those that invented the concept were to these organizations. This proximity, and being close to field problems, greatly contributed to the emergence of the idea in this firm.

Block 2 has one marine technical consultant firm (MCG), six people from Framo engineering, Statoil, and Rasmussen, a shipowner. Block 3 has engineers from firms involved in the Yme oil field, under development by Statoil. This is one of the oil fields where STL is going to be used. The other members of this block are field developers (Statoil), marine consultants (MCG), STL developers (APL), the classification firm DNVC, and Stolt Comex Seaway a ship owner operating supply ships. The only oil field under development in the network at this time is Yme.

Block 4 contains engineers from Statoil and Norsk Hydro, another Norwegian oil company, which later will be connected to installation of the STL buoy at one of their oil fields. Other members of the block include Marintek and DNVC. This block also contains Scana Staal that produce forged steel parts for the STL-buoy.

Using the structural equivalence data, the 1991 network is transformed to a block model. Table 3 shows the reduced block matrix with densities within blocks (diagonal) and between blocks, the overall density (alpha) is 0.06. The table displays all densities greater than alpha in bold type instead of using the conventional (0, 1) bifurcation. The actual densities reveal how the block members are connected within and between blocks. The blocks are more densely connected within than between them; one exception is that block 1 and 4 are more connected than the total density of the network. Block 3 is less connected to any other block at this time, as this oil field is in the early development stage. The low between block densities indicate that there are few relations between the blocks at this time. Since each block, or niche, is working more independently of each other, the densities are low.

Table 3: 1991 Reduced Block Matrix. Density within and between blocks of structurally equivalent actors. The diagonal shows the density within each block, alpha = 0.06

	Block 1	Block 2	Block 3	Block 4
Block 1	**0.13**			
Block 2	0.03	**0.16**		
Block 3	0.01	0.01	**0.12**	
Block 4	**0.08**	0.02	0.03	**0.13**

Structural equivalence blocks, 1993-94: field preparations

During 1992, engineers working at BP Harding, an oil field in the British sector of the North Sea, enter the network, together with Saxlund which fabricates the STL-buoy. Two ship owners (Ugland Offshore and Bergesen) and an oil company (Conoco) are also added. During 1993, engineers from three more firms join the network: a ship builder (HMV doing retrofitting of tankers to use the STL-buoy), a mechanical workshop (Nymo) that is assembling the buoy, and an oil field (Heidrun). There are now 92 engineers in the network. Early in 1993, APL was founded to prepare field installations of the buoy and its installation at oil fields.

Framo Engineering developed STP during 1994. APL continued working on field installations of the STL-buoy. Engineers from seven firms are added to the network. Six of them are working on field installations and one, NGI, is attached to the APL development block supplying geological data, which is important for the anchoring system. In this period a Statoil engineer, a former diver, get an idea for creating a suction anchor to solve anchoring problems on totally flat seabeds. This has since become an important feature of STL installations.

Because of new activities, STP development and field installations of STL, the 1994 network has a different structure than the 1991 network. Block 1 and 2 are STL development blocks. Block 1 membership is concentrated on the parts and knowledge supply side, and the development work, including an oil field, BP Harding. Statoil, Norsk Hydro, and Conoco are all partners in oil fields that install STL. Brd. Johnsen, Nymo, Saxlund, and Scana Staal produce parts or

assemble the STL-buoy. HMV retrofits tankers to be used with STL. DNVC, Marintek, and NGI are consultants for materials, anchoring, and geological data.

Block 2 has the oil fields and firms in the field development of STL. There are three oil fields (BP Harding, Heidrun, and Yme) and the firms participating in the STL development of these fields. This block also contains ship owner Bergesen, a future user of the STL- buoy.

Table 4: Block model of the network in 1994 with four structurally equivalent groups. The numbers in parenthesis indicate the number of people in each firm (firm name shows employment in 1995)

Block 1	Block 2	Block 3	Block 4
APL (20) Statoil (1) BP Harding (1) Brd. Johnsen (4) DNVC (2) HMV (2) Marintek (2) NGI (1) Norsk Hydro (1) Nymo (1) Saxlund (1) Scana Staal (1) Conoco (2)	APL (2) Statoil (5) BP Harding (1) DNVC (2) Heidrun (1) MCG (2) Norsk Hydro (1) Yme (1) Bergesen (1)	APL (1) Statoil (7) ABB Vetco (1) BP Harding (4) Centrilift (1) DNVC (1) MCG (1) Maersk (1) Marintek (1) Rasmussen (2) Schlumberger (1) Stolt Comex Seaway (2) Ugland Offshore (2) Coflexip (1) Simrad (1) Yme (2) VMO (1)	APL (2) Framo (7) Statoil (12) DNVC (4) Ugland Offshore (1)

Block 3 has two oil fields (BP Harding and Yme) and most of the firms doing field installations including supply and offtake ships. These firms are connected to APL and Statoil through the projects that involve installation of the STL buoy. Block 4 has the developers of STP. It is dominated by Framo Engineering and Statoil, and there are links to APL and one ship owner.

DNVC does the classification work of steel structures and retrofitted tankers. Table 4 shows the structural equivalence analysis of the 1994 network.

Table 5 displays the reduced block matrix. The network density within Block 1, Block 2, and Block 4 is high. Within each block, members are mainly connected to each other. There are some cross block ties. Block 1 is connected to Block 2, and Block 2 is connected to Block 4. Block 3 has a low density. Block 3 members are less in contact with each other, but all are connected to APL and Statoil; this is because the block members are structurally equivalent through their ties to APL and Statoil. These members are preparing field installations of the STL-buoy. Since installations are in preparation phase, the network has low density, most of the ties are directed mainly at APL and Statoil, during installations they will need to get in contact with each other to coordinate installations.

Table 5: 1994 Reduced Block Matrix. Density within and between blocks of structurally equivalent actors. The diagonal shows the density within each block, alpha = 0.07

	Block 1	Block 2	Block 3	Block 4
Block 1	**0.12**			
Block 2	**0.08**	**0.22**		
Block 3	0.05	0.04	0.04	
Block 4	0.03	**0.14**	0.01	**0.17**

Structural equivalence blocks 1995: field installations

We can interpret the four structurally equivalent blocks as activity niches (Burt & Talmud, 1993). Appendix table 1 exhibits the analysis results. Block 1 consists of the value chain of firms that engaged in STL development, fabrication, retrofitting of ships, and installation (including consultants and users). Most of the people working with STP, the higher level managers, and two potential users, are members of Block 2. This block consists mainly of participants in the development of STP. Block 3 includes firms that deal with oil field supplies and marine consultants that are required for STL/STP installation and use. Block 4 contains a number of oil fields and firms working with field installations including ship owners that are, or may become, users of STL/STP.

Table 6 shows the density within (diagonal) and between all blocks. Off diagonal cells indicate the density between blocks. The density of the network is 0.07. Between Blocks 2 and 4 there is a higher density than for the whole network. The connections are between the higher level engineers managing the projects, who have most of their contacts among themselves and towards the oil fields. None of the blocks are isolated from each other. There are very few relations between Blocks 2 and 3 due to the fact that STP has not yet been installed at any oil field during data collection. The connection between Blocks 2 and 4 indicates communications necessary to adapt STP to oil field installation requirements. The change of block location between 1994 and 1995 from Block 4 in 1994 to Block 2 in 1995, shows that the STP developer's connection to the STL developers is more important (The first CONCOR separation has Block 1 and 2 within the same block). At this time APL works on field installations and testing.

Table 6: Density within and between blocks of structurally equivalent actors, 1995. The diagonal shows the density within each block. The density of the entire network is 0.07.

	Block 1	Block 2	Block 3	Block 4
Block 1	**0.10**			
Block 2	0.05	**0.30**		
Block 3	0.04	0.01	**0.12**	
Block 4	0.06	**0.10**	0.05	**0.15**

By comparing the block models from 1990 and 1995, we find that there are substantial changes in relations among actors. Introducing new actors during the development and establishing new relations changes the network structure between both existing (in 1990) and new actors. The structural equivalence analysis for 1990 indicates that there is an existing structure that will support later development. The structure in 1995 describes specialized resources that are used in the value chains from development to oil field installations. The 1995 structure reflects ongoing activities that are shaped partly by the existing structure and partly by changes induced by the development of the technologies.

DISCUSSION AND CONCLUSION

The creation and use of Corporate Social Capital

The employees of firms are embedded in multiplex social systems, which may provide access to complementary resources. The most central engineers in this study all had long careers with experience from several firms. The relations of firms were transformed into personal relations when they did joint projects. Similarly, people brought their personal relations to effective use for their employers. This combination of firm specific and personal relations produce Corporate Social Capital (Gabbay & Leenders, 1999). This case study demonstrates how personal relations are used to informally organize a project that later was formalized by establishing a new firm (APL) and by formalizing contracts for suppliers.

This study demonstrates how access to social capital can be used effectively. One of the most important findings is that the relations between the people who got the ideas for STL/STP were established early, largely as a result of job mobility and contacts during project work in the North Sea. This professional community developed continuously over the years, and it was greatly expanded during the development phase. Early relations were personal relations that later became part of the Corporate Social Capital. When the project was formalized, relations that were organizational relations also became personal relations. Their familiarity with the people and the firms in the network enabled efficient mobilization of resources to complete the innovations within short time frames.

Corporate Social Capital enables technical discussions. Participants depend on past interactions to develop similar cognitive representations (Garud & Rappa, 1994; Pattison, 1994). However, few studies investigate how long it takes to create cross disciplinary understanding. This study indicates that intellectual resources are based on existing social capital. They built the necessary knowledge and established the amount of social capital that was necessary for the innovations during their long careers. We can conclude that social capital is effective not only because of trust (Axelrod, 1984; Krackhardt, 1992; Oliver, 1997; von Hippel, 1988), or because of shared frames of reference (Pattison 1994; Rentsch 1990). Just as important, the developers knew the whole social structure with all its subdisciplines within which this technical and economic behavior took place. Knowledge of the whole network enabled the construction of safe and reliable technologies (Pinkus et al., 1997). This knowledge reproduces whole network effects on social

capital. Studies of social capital henceforth should include not only direct effects but also indirect effects of the whole network.

The social network position of the developers

The ideas for STL/STP surfaced among a group of people with close proximity to institutions and firms that developed fundamental new knowledge and components that enabled these technologies. Their age and experience coincided with fundamental breakthroughs in knowledge, which occurred within their social networks. Thus, they connected users and knowledge developers, which gave them an ideal network position for technology development. They acted as brokers between two network clusters that only may be weakly connected to each other. This brokerage position enabled the combination of resources into new entrepreneurial activities (Burt, 1992).

Von Hippel (1988) stressed the importance for developers to be connected to users to be able to create efficient innovations. This study extends this finding to include close connections to the supply side as well as the demand side, particularly since the supply side developed the necessary knowledge to produce the innovations. User participation secured adaptation of all interdependent processes. In addition to these groups, the network also included contacts to firms operating oil fields and firms that were engaged in field installations, supply, and transportation. The social capital of the innovators was productive as a total network effort as well as input to the innovation process within the firms APL and Framo Engineering. Their marginal network position on the fringe of the core oil industry freed them from traditional thinking, allowing radical innovations to be completed (Tushman & Anderson, 1986).

The developers were connected to other players with strong and weak ties (Granovetter, 1973, 1982, 1985). Strong ties to Statoil employees gave them access to the necessary resources to complete the projects. Weaker ties within the larger structure connected them to a large set of suppliers necessary for developing and installing STL/STP at oil fields. This study clearly demonstrates the importance of social network position for the emergence of innovations. We also demonstrate that it is important to map complete networks to understand how social network positions enable innovations. Without this position in the network, the ideas and the development of STL/STP would probably not have been accomplished. The total resource base that was necessary for

these innovations was distributed across a large network. By connecting formerly disconnected actors, new cooperative relations were established to do different tasks in the development.

Integrating a specialized structure

Complex innovations cannot be fully understood by any single person; it is the combination of knowledge from several people that makes the system work. Experts must have an overall picture. They must perceive the boundaries of their knowledge, recognize what is not known within their own field and to whom they can turn for the expertise to produce the technologies (Pinkus et al., 1997). Social networks are effective for asset mobilization because they can make available social capital to combine complementary knowledge. In this way they can take advantage of the network.

The experience and the social capital of the innovators in this project enabled them to combine resources in novel ways. During this innovation process, mobilization of additional complementary resources was accomplished by adding more relations to the existing network, and by connecting previously unconnected people in the network to each other. The success of the project demonstrates how social capital is used to accomplish complex tasks and coordinate several experts from several firms. Again, it demonstrates how important it is to analyze network effects on social capital.

Structural equivalence analyses indicate that roles are distributed among the firms according to similarity in communication structures. Burt and Talmud (1993) established that structural equivalence can be used to identify niches with populations sharing common resources. Structural equivalence indicates groups of actors with shared cognitions (Carley, 1986; Galaskiewicz & Burt 1991). Therefore, social capital can be analyzed as a property of a social niche. In this study, structural equivalence analysis divided the participants into four blocks representing the specialized resources for the development and field installations of the innovations. This structure changed as the development tasks proceeded. Ties between the blocks got stronger (higher density between blocks) as closer coordination became necessary during field installations. This analysis illustrates that block modelling is a useful procedure for detecting specialization of resources within a social structure. Relations within and between blocks display interdependencies between

actors, and the links that coordinate the specialized task structures. Thus, social capital should also be analyzed to identify niches of specialized resources and how they are connected.

Since the social capital of individuals and organizations is part of a larger structure, each actor's social capital is embedded in other individuals' social capital. Through their long careers, spanning several organizations, the core group of innovators carried with them a mix of relations created during their education and created while working in other organizations. Thus, Corporate Social Capital was transferred between organizations by individuals, and made useful in other contexts for other organizations, as well as for their former employers that became participants in these innovation projects. In a large network all resources are interdependent, and the total network effort of interrelated Corporate Social Capital produced these innovations.

ENDNOTES

1. Since 1990 BP and Statoil have operated a strategic alliance for international operations.

2. Traditional technology requires fluids and gas to be separated before pumping. In Multiphase oil production there are simultaneous flows in one pipe of different substances (oil, gas, and sea water). It also uses multiphase boosting, which is the ability to add energy to an unprocessed oil well flow. Boosting consists of injecting sea water, gas, and methanol back into the well to maintain well pressure. Methanol is used to keep the risers from clogging. This process more than doubles the utilization of the resources in an oil well than under conventional oil extraction. Framo Engineering developed different multiphase booster systems in conjunction with some oil companies. They also developed separators that remove oil, water, gas, and solids from crude oil, and multiphase flow meters to monitor and control oil wells (Framo Engineering, no date; Steine, 1994).

3. The CONCOR method divides a social structure into blocks based on similarity in network relations. Using correlations of relations the network is first divided into two blocks where the members within each block has a high correlation of relations. The procedure continues bifurcating the blocks. How many partitions the procedure should run is judged by the person doing the analysis. Here we decided to do two partitions, which made sense when judging block membership. After the CONCOR procedure had identified four groups, we ran QAP correlations testing 1000 randomly grouped networks to see if a better fit could be found, which did not occur in any of the tests.

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APPENDIX

Table 7: Block model of the network end of 1995 with four structurally equivalent groups. The numbers in parenthesis indicate the number of people in each firm (firm name shows employment in 1995)

Block 1	Block 2	Block 3	Block 4
APL (23)	Framo (6)	APL (1)	Statoil (4)
Statoil (2)	Statoil (11)	Statoil (6)	BP Harding (6)
BP Harding (1)	MCG (1)	ABB Vetco (1)	DNVC (1)
Brd. Johnsen (4)	Rasmussen (2)	Centrilift (1)	Heidrun (1)
DNVC (3)		DNVC (1)	MCG (1)
HMV (2)		MCG (1)	Ugland Offshore
Marintek (2)		Maersk (1)	(1)
NGI (1)		Marintek (1)	Yme (1)
Norsk Hydro (2)		Rasmussen (2)	Bergesen (1)
Nymo (1)		Schlumberger (1)	Simrad (1)
Saxlund (1)		Stolt Comex Sea-	
Scana Staal (1)		way (2)	
Ugland Offshore		Yme (2)	
(1)		Coflexip	
Conoco (2)		VMO (1)	
Bloom & Voss (1)			