CREATIVITY IN SOCIAL NETWORKS: COMBINING KNOWLEDGE IN INNOVATIONS.

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Abstract

Creativity in technology innovation arises from interaction in social systems. One person cannot be creative alone. We should study technology innovation as the ways that creative minds interact with others to facilitate and take advantage of creativity. To show the importance of interaction in complex technologies, my paper looks at technologies that are more complex than a single individual can fathom. The creation of complex technologies requires a combination of complementary disciplines. This article describes a group of creative engineers that use three knowledge breakthroughs in different fields to construct two technologies for floating off-loading and production of oil. Social network analysis reveals how nested networks of industries, organizations, and individuals contribute opportunities and resources to complete the innovations. The firms where these innovations take place are located on the fringe of the oil industry, and not immersed in existing technological paradigms. The initiators and their closest collaborators have careers that span several firms in different fields in shipping and oil activities. These networks embrace all sectors of the oil supply industry. The initiators have direct links to all the firms that

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supply the fundamental knowledge. They and their connections mobilize all the necessary resources to complete and install the innovations at oil fields, altogether 113 people in 32 organizations.

INTRODUCTION

This paper discusses creativity and problem solving in the invention of complex technologies. A complex technology requires knowledge from more than one discipline. The vast knowledge that enters the technology is rarely understood by any single individual. The social context of creativity is nicely shown by analyzing multi-level nested structures of industries, firms, and actors. The network position of firms within an industry exposes them to a set of work processes and problems. Career mobility enables people to build heterogeneous networks that include cross-disciplinary contacts. A creative environment can take advantage of knowledge in different fields to produce radical innovations. Therefore, I will analyze creativity and innovations from industry, firm, and individual level networks that connect various disciplines. I analyze how career paths shape the social networks of individuals showing why some are in better positions than others to become successful innovators.

People are members of social systems that contribute to, support, or impede creativity (Kanter, 1983, 1988). Interpersonal creativity stands behind any radical innovation (Perry-Smith & Shalley, 2003). Radical innovations require knowledge at the research frontier. Such innovations require cross-disciplinary combinations of knowledge to produce the desired outcomes. Individual creativity and ability to deliver innovations depend on interactions in social systems (Amabile, 1996). Taking the ability to interact in interorganizational contexts as my focus, I show that social structure allocates useful contacts. The process of building the structure puts some people in more advantageous positions than others to innovate.

In this article I define creativity as thinking outside of general frames of reference that leads to generation of novel ideas, solutions to problems, or innovations. This concept of creativity is continuous, from incremental improvements to radically new solutions (Amabile, 1996). With this definition I see creativity as a starting point of all innovations (Amabile, Conti, Coon, Lazenby, & Herron, 1996). However, successful innovations also require mobilization of resources and organization. This study uses two cases of radical innovations to illustrate a social network approach.

Research has concentrated on individual creativity. Creative persons may be exceptionally talented and well trained (Amabile, 1988). Such research concentrates on creativity as an individual trait (see Barron & Harrington, 1981, for a review). However, recent writers have looked at the social processes that support or inhibit creativity (Amabile, 1996; Kanter, 1983; 1988). Woodman and Schoenfeldt (1990) suggest an interactionist model of individual creativity with person-situation interaction as main focus. This model is extended to individual interactions in groups, so that creativity lead to organizational outcomes (Woodman, Sawyer, & Griffin, 1993). Most following research looks at formal groups or organizations. However, creative innovations may originate in informal groups or social networks that span interorganizational networks (Perry-Smith & Shalley, 2003). Thus, a social network perspective complements research at individual and group levels, by formalizing and mapping social relations that enter into the creative process that eventually produces innovations.

That actors are parts of larger social systems can be seen in the discussion of industry wide factors that determine success or failure in innovations. These factors derive from the ways firms form parts of a larger economic and social structure of other firms. Their position in this structure either endows or constrains them with resources and opportunities (Granovetter, 1985). These social structures may span several firms, institutions, and contacts that help solve problems. They are the social capital of the innovators (Burt, 1992; Coleman, 1988). 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). Social capital enables the mobilization of complementary resources that are necessary in complex innovations (Greve & Salaff, 2001). As individuals and as employees of a firm embedded in these networks, people are propelled to or blocked from creating and innovating.

First, I discuss prior research on innovations from a structural point of view to identify what we know about firms as participants in innovation systems. This discussion contrasts studies of successful and failed innovations or innovation systems. These suggest social and institutional impediments to creativity and innovations. Second, A firm's network position combines with social capital accrued during the careers of engineers to enable the creation of complex innovations. I derive propositions from theories that analyze organizations and individuals as participants in multi-level, dynamic, nested social and economic systems. Finally, I apply these propositions to a case study of two radical innovations in the oil industry, STL/STP, by exposing the social structures that enable the innovations.

Previous research

Social networks explain the emergence of radical innovations at four main levels. Network position can provide either information advantages or disadvantages. Studies of networks at an individual level show the prevalence of interactions during innovations. Network analysis of alliances between firms reveal the interconnectedness of firms participating in innovative activities. Network alliances between firms can enable cooperation. Individuals must respond to and develop new ideas, find, and mobilize resources to refine ideas, enable production, and cooperate in execution of innovations. The third level looks at complexity and complementary resources at industry level. Complex innovations often require cross-industry networks to take advantage of combining knowledge and technologies from different domains. At the fourth level, we learn how institutional settings influence the actors' ability to question existing technological solutions and engage in creative innovations. At the institutional level, a firm's network position connects different disciplines and enables creative combinations of knowledge. Taken together, these interactions reveal how personal, firm, industry, and knowledge networks are nested into each other.

Studies of creativity and innovations. Early studies, comparing successes and failures of innovations, find that successful innovations are those open to external communications. When users participate in the idea phase and the process of completion, successful innovations are more likely (Rothwell, Freeman, Horsley, Jervis, Robertson, & Townsend, 1974; Rothwell, 1985). The importance of the innovating firm's supporting dialogue has remained a theme. Von Hippel (1988) reiterates this motif investigating myriad sources of ideas of innovations, starting in firms producing the innovations, and including all participants in the value chain.

Other research exploring internal properties of firms stresses openness to discourse. Looking for innovative cultures, Kanter (1983) shows that routines, existing activities, and the NIH (not invented here) syndrome curbs creativity. In contrast, interactions with diverse others support creativity. Exposure to alternatives enables people to use wider categories and come up with more divergent solutions (Kanter, 1983, 1988).

Researchers probe whether available time, type of information, or interaction most spark creativity in organizations. Creativity depends on personal interactions, which require time (Gann & Salter, 2000). Engineering designers problem solve better when they can both spend time on their own and face-to-face with coworkers (Nightingale, 1998; Perlow (1999). Researching the impact of information technology and product development, writers find that time for interaction over questions at hand dwarfs access to information as such. Introducing information technology to help people become more creative by itself helps less (Court, Culley, & McMahon, 1997; Salter & Gann, 2003).

Innovation in R&D alliances. Interorganizational relations promote organizational R&D. In the biotechnology industry, few firms can mobilize sufficient internal resources for R&D, patenting, clinical trials, governmental approval, production, and commercialization on their own. Strategic alliances help them grow and prosper (Powell, Koput, Smith-Doerr, & Owen-Smith, 1999). However, collaborations often fail because of mismatched complementarity, rivalries, social and cultural conflicts, and problems of communication and coordination (Omta & Rossum, 1999). Alliances without prior relationships often fail. Many problems related to the R&D process are rooted in lack of clear knowledge of what partners can accomplish, and how to organize an alliance (Niosi, 2003). Partner selection often misses the social and cultural aspects and the give-and-take aspects of collaboration (Erens, Stoffelen, van de Ven, & Wildeman, 1996). Since it is hard to predict how people should interact to innovate, if managers select partners based on prestige or market share, without pre-existing relations, the alliance will fail. Therefore, this paper looks at how social structures emerge over time to evolve into formal relations. Favorable positions and connections arise from career mobility and interorganizational work experiences. The success of an alliance depends heavily on partner selection, which in many cases can be a formalization of informal ties.

Connecting complementary knowledge. Complementary resources are only useful if innovators know about them. The knowledge behind technologies often resides in a network of firms, not in single firms alone (Afuah, 2000). Firms connected to other firms, or with employees that have experiences and connections across disciplines, have nested networks. Through these contacts employees learn about the resources colleagues in other disciplines command, and how they solve problems. Firms with such connections can more easily mobilize complementary resources than if they have to establish such connections anew.

In contrast, core firms within an industry often develop practice and beliefs in specific technological systems. They may dominate markets, becoming carriers of the dominating knowledge and technological paradigms. These firms rarely produce new technologies that break with the current paradigm, because they entrenched in the dominating knowledge paradigms. (Tushman & Anderson, 1986).

Similarly, firms that take their technology for granted during designing and running complex technologies may fall into the competency trap when searching for solutions to problems within their familiar paradigm (March, 1991; Vaughan, 1996). They are good at raising questions and solving problems within their own knowledge domains, by incremental changes of the technology, but not outside this frame.

In other words, frames of reference and cognition blind actors from raising crucial questions and mobilizing external knowledge to help solve problems. When actors lack knowledge outside their own domain, or exclude people with the required expertise in problem solving, organizational failures can occur (Weick & Roberts, 1993; Vaughan, 1996). If problems cannot be solved within their paradigm, engineers in such closed firms do not know whom to ask. Nor would they know how to communicate with those from other fields (Pinkus, Shuman, Hummon, & Wolfe, 1997). People who interact frequently tend to think in the same way, and trust best the information that comes from a set of known actors (Krackhardt, 1992). Discovering how knowledge and assets can be redefined and connected in novel ways requires heterogeneous networks that can expose people to diversity that can inspire and enable creativity (Amabile et al., 1996; Woodman et al., 1993).

Technology changes and institutional settings. Industries and technologies go through periods of creative exploration and innovation, and other periods of fine tuning, or incremental change (also labelled exploitation [March, 1991]). As industries go through these cycles, some innovations succeed, others fail, not always for the right reasons. Selection mechanisms may not favor the technologically best solutions. Selection in some organizational environments lands on bad solutions; institutional standardization may impede technology development; choice of the wrong technology may lead to a dead end. Breaking with an accepted path may be very difficult (Garud & Rappa, 1994; Van de Ven & Garud, 1994).

Radical innovations break with existing knowledge by combining new components in a new architecture.[1] To make such breakthroughs requires a change in the perception of causal relations, at the core of creativity (Henderson & Clark, 1990). These changes are the most difficult to construct and adopt. Connecting pieces of new knowledge requires cross-disciplinary contacts and knowing who can do what. Tushman & Anderson (1986) found that radical innovations mainly came from firms on the industry fringes. Not embedded in existing technologies, they discern deficiencies, and are more willing than core firms to take the risk of exploring alternatives, they are not bound by institutional norms of appropriate practice.

Theory of creativity in social networks

As other contributors to this volume point out, creativity has many expressions, from individual responses to problems, to ways of doing work and play. I focus on inventing complex technology. Complex technology is so complex that no single individual understands all aspects. A set of components must be produced with the help of several disciplines, following which these components are connected together to produce the desired outcome. The pattern of these connections are its architecture. A radical innovation has both new components and new architecture (Henderson & Clark, 1990).

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[1] Architecture refers to the ways the components are connected.

The theory I develop focuses on how individuals' positions in social networks enable creativity. I will look at conditions related to interfirm networks, how careers crossing heterogeneous firms develop social networks that enable understanding cross-disciplinary knowledge. Finally we will see how a central network position helps mobilize resources for cooperation in complex innovations.

Nested multi-level networks. An important concept for studying innovative settings is nested systems. The literature studies innovations from at least four different levels, the industry level, inter organizational level, firm level, and individual level. When conditions from each of these levels affect innovations on lower levels, we refer to nested systems of relations. Such nested systems can be viewed as multi-level social networks. Since creativity and innovation activities may exist in firms in different positions in these networks, the interaction of parts of the system may spark creativity elsewhere. The study of creativity alert us to the structural properties of systems. Drawing on this literature, I suggest a theory explaining how structures enhancing creativity and innovations evolve.

Individual creativity in organizational settings. Individual creativity flows from "embeddedness" or the cross-cutting of diverse social networks (Granovetter, 1985). Organizational structures, job designs, and career experiences shape opportunities to interact. Organizations shape opportunities to interact differentially depending on employees' positions in hierarchies and task structures. Those in a favorable network position often follow developments in different fields than their own. Through their careers, they are also likely to know more people in other organizations. Since new knowledge develops in different fields at varied speeds, conversations with other engineers, customers and representatives that are part of their value chains, often discuss their ideas, resulting in innovations (Afuah, 2000).

People who have held many positions in different organizations are more likely to develop social capital that spans several organizations (Greve & Salaff, 2001). In contact with and collaborating on joint projects with several organizations, they can draw on corporate social capital. Corporate social capital refers to relations embedded in positions that are specific to firms (Gabbay & Leenders, 1999). These relations are connected to individuals who can draw on them for projects in other settings.

Some individuals have contacts to people in other departments, firms, and institutions that may possess or develop knowledge that can have an impact on their current work. These individuals may have contacts to the academic system and other knowledge producing firms that may come up with new knowledge components that can solve current problems. These contacts are the social capital that individuals can draw on to reach specific goals (Bourdieu, 1986; Coleman, 1988; Burt, 1992). Thus, from these findings on embedded social networks, I propose:

> Proposition 1: People who are embedded in social networks that span several firms and institutions, are more likely to be creative innovators than those lacking such connections.

This hypothesis depends on people being able to:

1. Build social networks that embed them into nested networks at several levels, which are necessary for spanning cross-disciplinary networks.
2. Understand implications of breakthroughs in science from other disciplines, and
3. Communicate with professionals from other disciplines.

I look into what it takes to develop relations that are embedded in several different networks.

Careers & knowledge. Career mobility occurs in dynamic network structures (White; 1970). Heterogeneous contacts expand people's opportunities to collaborate with people from other disciplines. There are diverse patterns of choosing partners for technical advice. The homophily principle influences choice of network partners. Since people are attracted to those that are similar to themselves, this may limit people's networks and gives them less information (Burt, 1992; Granovetter, 1973; Lin, 2001). Others whose careers span several organizations with different task domains will meet a diverse set of people. Cross-domain relevant knowledge is likely to be non redundant information that can enhance creativity (Csikszentmihalyi, 1996).

Likewise, when organizations chose partners, cultural similarity attracts organizations (Pinfield, 1973). Since trust and mutual solidarity are the basis of establishing and maintaining both personal and interorganizational relations, homophily in interorganizational relations can limit exposure to diverse disciplines. It would be harder to break through inherited paradigms (Gherardi & Masiero, 1990; Krackhardt, 1992; van de Meer & Calori, 1989).

In contrast, connections between different firms will not only diversify people's networks. They also create trust and access to new knowledge frontiers. Interorganizational networks benefit knowledge transfers between organizations if there are personal relations between employees (Swan, Newell, & Robertson, 1995). In contrast, lack of personal networks between organizations impede such knowledge transfer (Groenewegen, 1995).

Therefore, I propose:

> Proposition 2: People who have a career path through several different firms are more likely to have interdisciplinary networks than people without such careers.

This hypothesis rests on an assumption that having the networks is a necessary but not sufficient condition to take advantage of interdisciplinary networks. This requires one more condition. To understand what other disciplines can offer to solve complex problems, people need to share frames of reference.

Frames 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). Communications depend on developing a shared frame of reference to understand cross-disciplinary contributions, and understanding the final goal of an idea. Cross-disciplinary communications further rest on understanding how knowledge from other disciplines can produce desired outcomes.

In solving complex problems, each specialist provides part of the expertise necessary to the total knowledge required. Professionals communicate and tend to trust each other when they have common denominators (Bouty, 2000; Oliver, 1997). Their past interactions help develop similar cognitive representations (Garud & Rappa, 1994; Pattison, 1994).

Social relations produce and maintain intellectual resources. Having a career path that crosses many firms and many projects gives an opportunity for life-long learning and developing shared frames of reference with other disciplines. Such networks enable technology developers to see implications of progress in knowledge in other fields, and thus creatively join new components into a new architecture to produce radically new technologies. In contrast to incremental changes, complex innovations like those studied here are only possible by drawing on the expertise of several participants from different fields. Only through interdisciplinary networks can actors join their resources to cooperate on such innovations. The network brings together complementary resources (Teece, 1986).

> Proposition 3: Having careers spanning several firms and projects increases people's ability to communicate and collaborate across disciplines.

Complementarities. Complex innovations bring together new components in new patterns (architecture). So long as people are doing routine work, they can use their familiar suppliers. For new projects, however, people need to mobilize new sources of material and knowledge. They will access the components from a set of different disciplines. Putting them together also requires cross-disciplinary expertise.

To start a search for complementary resources, the actors must recognize how components and the knowledge attached to these ingredients interact (Boland, Tenkasi, & Te'eni, 1994; Håkanson, 1989). Past whether the supplier can deliver a new technology, can they also solve new problems?

Knowing whether suppliers are problem solvers requires an intimate knowledge of what they can accomplish (Arora & Gambardella, 1990). One's social network position determines access to such information about actors. People occupying central positions in a network that crosses disciplines have the most contact with those in other practices (Arora & Gambardella, 1994). They can more readily discover where to obtain complementary resources.

People need to share frames of reference to know how to take advantage of these complementary resources. Social position is associated with an actor's cognitive representation and determines the resources an actor is able to mobilize for innovation (Pattison, 1994). For instance, engineers need to understand how to take advantage of a novel component to solve problems. This is helped by understanding how components developed in a different discipline can contribute to the sought after outcome.

Proposition 4: The higher the network centrality of actors the more able they are in mobilizing complementary resources.

RESEARCH METHODS

Interviews and data collection

Using a mix of qualitative and quantitative methods can provide both attention to detail and processes, and generate generalizable results that contributes to and supports theory. The qualitative part of the method involves defining the content of the relations through interviewing to cover the same content across several relations and respondents. The interviews and documentation from the firms augment the history of the innovation processes and the development of the networks. At the same time, a quantitative social network analysis prevents the researchers from falling victim to the respondents' frames of reference, because the perceived networks may not be the same as the actual social relations (Krackhardt, 1992).

After reading the documentation of the technologies and talking with the project coordinator for STL/STP, I learned the language and concepts of the technologies. This enabled me to talk to the developers. Initially, I interviewed all participants in the development project for STL/STP at APL, Statoil, and Framo Engineering, and employees of some of the other firms that participated. Based on these interviews, I made a name list of all people who had been involved in the development and commercialization of the technologies. For each person on the list I asked the respondent how long they had been related, and how often they communicated. I emphasize relations that contain technical discussions and problem solving. I collected most data in person, through face-to-face or telephone interviews. Additions of names to the list are included for the next interviewees. I also asked people if they knew the contacts of their own relations. I systematically asked a subset of these named people to verify these relations (Burt & Ronchi, 1994). The network consists of 113 individuals with 919 relations, of which 878 were verified first hand and 41 relations were second hand information.

To analyze the duration of relations I use the data on how long a connection is active. The map of relations and the date of establishment only cover data for the network that is relevant for the development of STL/STP. Networks that started before 1990 are relations that later become involved in the technology development. This network is a subset of the professional networks of the participants. I do not have information about the relations that do not become vital in the development of STL/STP. The reason to include the earlier, partial networks is to establish the duration and evolution of structures that become involved in the development process. The network data that cover the period between 1990 and 1995 include all persons who at some time has a connection to the project. Some people also left the project during this period.

Network measures

The data include 113 individuals from 32 firms. Network measures can be divided into two classes: centrality measures are related to individuals and their position, and structural equivalence shows network clustering. In this paper I use Closeness centrality to show the centrality of members in the network. Closeness centrality is a measure of people's ability to reach everybody else in the network through optimized paths (Freeman, 1979). People with high centrality can reach everybody else in the network through fewer other people, than less central people who have to go through more connections using longer paths to reach others. Central people need not have many direct ties as long as they are connected directly to others with many ties.

Structural equivalence means that actors have similar network positions in terms of connections to others. Structural equivalence defines actors that have similar input-output relations and belong to the same social or economic niche (Burt & Talmud, 1993). Structurally equivalent actors have a similar social position and share communication sources and tasks. Structurally equivalent actors participate in the same domain of operations, which corresponds to value chains in economic terms. They are on the same level of a value chain. Structurally equivalent actors may or may not be connected to each other. Their networks are similar by being connected to similar others.

Block models show how the network can be divided into blocks of actors who are structurally equivalent. These models show communications within and between blocks (Wasserman & Faust, 1994). For presentation of block models, I show within (diagonal) and between block (off diagonal) densities of relations. Network density is calculated from the number of existing relations: l, in a network of N actors:

$$\text{Density} = l/[N(N - 1)]$$

Density = 1.0 if everybody is in contact with everybody else. The network densities show to what extent the block members are interconnected (within block) and the density of connections to other blocks to which they are connected.

RESULTS: THE DEVELOPMENT OF TWO OIL TECHNOLOGIES

Presentation of the STL/STP technologies

Two technologies for floating uploading of oil and production of oil, Submerged Turret Loading and Submerged Turret Production, (henceforth STL/STP) are stellar examples of developing complex technologies. Three independent breakthroughs in knowledge occurred prior to the development of these innovations. One was the development of simulation models for stable position anchoring in high waves in open seas. The firm Marintek developed these models, building on fresh knowledge of wave dynamics. Framo Engineering constructed a rotating connector to seal oil flows at high temperature and high pressure. From the field of physics, new knowledge of multiphase flows and pumping solved the problem of pumping oil and gas through the same risers (the pipe connecting the well-head with the pumping unit), and reinjecting gas and sea water to maintain well-pressure.

STL is a submerged cone shaped oil loading buoy that is connected to a tanker through a hole in the bottom of the bow of the ship to load oil off-shore from a production platform. The buoy anchors the ship to the sea bed, and the rotating connector enables the ship to turn so that it always faces the wind. The anchoring system is the technologically most advanced part, which must be designed and constructed separately for each location. As a result of this innovation, in late 1993 an engineer in Statoil got an idea for a related innovation, STP, that uses a modified STL buoy as a connection between an oil well and a tanker for floating multiphase oil production, thereby eliminating the need for oil platforms. The tanker has a multiphase production unit built into its bow compartment, that connects to an STP buoy. They can pump crude directly from the well-head, separate oil from gas and sea-water, and reinject gas and sea water into the well.

The development of the technologies

The breakthrough STL concept emerged among a group of people working at MCG (Marine Consultants Group). Instead of making oil pipelines from the fields in the North Sea, Statoil and other oil operators decided to start production using buoy loading to tankers at the field, while they planned pipelines. This process, despite a lot of problems, was so successful that the oil field operators cancelled plans for oil pipelines. MCG works on improving buoy loading. The main problems are related to weather and no standardized way of connecting a tanker to the off-load devices. The weather is the most serious problem, high waves and shifting wind directions cause constant stoppages with dangers of oil spills.

The original concept for STL comes from 1004.[1] He is aware of new progress related to wave dynamics through close connections to 1013 (the most important person of the group) and 21001, key in the development of anchoring models. 1004 is also connected to 3012, who from 1983 to 1991 was managing director of Framo Engineering that developed the rotating connector around 1990. The idea of a totally new concept for off-loading is conceived and elaborated together with 1013, 21001, and other engineers working in MCG in 1990. They begin working on a prototype and they have a working prototype in 1992. 1004, MCG, and Statoil establish the firm Applied Production Loading (APL) in early 1993 to dedicate the firm to STL. Almost half of the employees from MCG followed 1004 and 1013 to join APL.

The developers of STL draw on other firms and research institutions. Most of the APL employees are educated at The University of Science and Technology in Trondheim (NTNU) as marine engineers. 1013 was a faculty member at NTNU before joining MCG in 1990 and, later, APL. Several of his former students participate in the project. The developers also have work-related contacts made through their career paths working in other firms and several projects in the North Sea. Another factor that contributed to the development of their networks is using other firms' offices and facilities during project work. This is common in the oil industry in Norway. It increases their exposure to other firms, and it creates many useful contacts for future work.

These innovators are positioned between organizations doing basic research in technology relevant to buoy loading and users of buoy technologies. Through their work at MCG they are familiar with the problems of conventional buoy systems. The close connection between 1004 and 1013 to Marintek, Statoil, and Framo Engineering, combined with the problems they are working on at MCG, creates the setting for developing the concept for

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[1] I use numbers as anonymous person identifiers for the social network data. The right most three digits are person numbers, the left most digits refer to the firm number.

STL. The developers' connections to Statoil and BP make the first field installations feasible. While each installation is less costly than the traditional buoy loading technologies, such radical departures from existing technologies are risky. Nevertheless, the payoff of this innovation is considerable. By the end of 2003, 8 years of reliable production and verifications have supported the models, and expanded the areas of deployment of these technologies. (See APL's website for further information: http://www.apl.no/)

At the same time as STL is developed, researchers in a group of firms and research institutes solved the problems of multiphase flows and pumping. By maintaining oil well pressure, the process more than doubles the yield of an oil field. Late in 1993, 3012 in Statoil, while working with APL on the STL project, thought to combine multiphase pumping with the STL buoy. He suddenly realized that instead of the inboard crude oil connector, they should put a multiphase production unit to draw crude oil directly from the well head. He takes his idea to his colleague and long time friend, 3005, and together they develop the concept of STP. As former managing director of Framo Engineering, 3012 has a good understanding of its capabilities. He discusses with them the possibility of developing multiphase pumping units small enough to be placed in a ship connected to a modified STL buoy to extract crude oil directly from the well head. If this concept is feasible, it will eliminate the need for an oil production platform. Framo Engineering accepts this project, and after working on it during 1994 comes up with a working prototype. Since the unit is located in a ship, it can be used at several fields, which makes possible extracting oil from small fields without leaving derelict installations remaining behind them.

The social networks of the initiators of STL/STP span all the firms and R&D institutes that developed the basic knowledge. All are directly connected to people developing this knowledge. Their knowledge of the capabilities of the different firms they need to develop the technologies, enable a selection of discussion partners to make the technologies feasible and operational. The engineers have connections to firms with experts in wave dynamics, anchoring (A former diver in their network comes up with an idea of a suction anchor for flat sea-beds), metallurgy, geology (including oil and sea bed geology), risers, pipelines, pumping, platform construction and running, shuttle tanker operations, energy producers, and suppliers of many kinds of equipment. Another set of experts is brought in 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. These different types of expertise are necessary to incorporate component and process dependencies of the technologies. They have to mobilize this expertise early to incorporate all the necessary knowledge from each partner, so that they can take advantage of this knowledge while developing the innovations.

The innovations are completed within a social network that contains all the necessary expertise. However, this social network does not contain top level management, for good reason. Sometimes a social structure may contain people that can limit or stop activities, these are a social liability (Gabbay & Leenders, 1999). The engineers run the project; they obtain budgets and permissions to go ahead after they have started the development. They did not seek approval before they could demonstrate that the project is feasible. In this manner, loosely coupled, trusting relations in a network of small interconnected units avoid liabilities of the social structure. The engineers were careful not to involve management too early. If there were tighter coupling between management and engineers, the probability of doing this innovative, yet unproved project would have been much lower.

Compared to the big oil companies, the interindustry network position of the core firms developing these technologies is marginal. All the engineering firms and research institutes that participated are very small, none of them have more than about 30 employees. As a result, they did not fall victim of conventional thinking that plagued the established oil companies. Statoil as the main collaborator, is a newly founded oil company, which despite its size of approximately 18,000 employees, is a small company compared to other leading global competitors. As a newcomer to the oil industry Statoil has no strong norms about what constitutes appropriate technologies (Henderson & Clark, 1990). Statoil observes the inefficiencies and defects of the traditional offshore oil technologies that had been developed under far more benign environments than the North Sea. Since its social structures did not create liabilities, it was more open to innovations.

The evolution of the network structures

The STL network. The oldest relations were established before 1970; the dyad that developed the concept for STP dates from 1962 (3012-3005). By 1970 there are two clusters: one is a clique composed of 21001, 3012, and 3005. The other is a star-shaped network with 1013 in the center connecting 1023, 1004 (The STL originator), and 3017. (Figure 1). In the late 1970's, a newly founded relation between 21001 and 1013 connects the two clusters and three more people enter the network.

<<< Insert Figure 1 about here >>>

During the following years their networks develop as a consequence of having several jobs with several firms. Their long careers within the marine-based oil industry endow them with social capital that span 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. Altogether 32 firms participate in the development of STL/STP, including 21 of the 44 firms that had employed one or more of these people. This demonstrates how the engineers build their social capital during their careers, and become part of the corporate social capital of firms they had left. Through their careers the innovators obtained a social network position with direct contacts to organizations that do fundamental research. They also connect directly to users of the technologies. This makes it possible to combine and apply new knowledge to radical innovations.

The network clusters into four structural equivalence groups of the firms that participate in the development of the concept of STL in 1990. At this phase of the development, there are no contracts, all the relations are informal contacts that help create the concept. They all give their inputs to the originators of the STL concept. 57 people from 12 firms participate in the network that develops the concept for STL. All contribute knowledge and solutions to different problems. They represent all types of input from the engineering firms to producers of parts and suppliers to oil field installations. There is also a person working at an oil field that Statoil develops, which later is among the first users of STL. By the end of 1992 the group at MCG has a workable prototype.

<<< Insert Table 1 about here >>>

The reduced block matrix, Table 1, shows that within block densities are highest in block 2, which is also connected to blocks 1 and 4. Block 3 is the least connected block, both within and to other blocks. The nature of the tasks within the blocks are clearly reflected in the reduced block matrix. There is a clear need for coordinating the STL value chain block (1) and the oil fields where the installation is taking place (block 2). The presence of some of the most important people of both APL (1004) and Statoil (3005 and 3012) in block 2 can explain the high within and between block densities of this block. Particularly, there are several connections to block 4 and 1. This shows how closely the development of STP is to STL developers and the future users of this technology.

Using Closeness centrality measures from the 1990 network, the most central people are all closely related to the group from MCG that came up with the STP concept, 1013, 1004, 3005, 3012, 21001, and 24001 (who has a doctorate degree in wave dynamics) are all among the 8 most central actors. They come from MCG, Statoil, Framo Engineering, Marintek, and NTNU/SINTEF (A technological research institute). 3012 is at this time the managing director of Framo Engineering, the firm that supplied the rotating connector, 21001 works at Marintek that developed the anchoring models. The close relations among this group of people put 1004 and 1013 in an ideal position to come up with the concept of STL. They were in the cross-roads of all the relevant technology development, and they worked on buoy loading problems connected to two important users of buoy loading, Statoil (3005) and Norsk Hydro (through 24001 who became employed at Norsk Hydro to work with STL deployment). Less institutionalized than the big foreign companies, these oil companies are more open to radical innovations.

The STP network. After 3012 and 3005 work on the concept for STP and discuss it with Framo Engineering, Statoil decides to start development of STP. During 1994, Framo Engineering constructs a workable prototype. At its largest size in 1994, the STL/STP network counts 111 people from 32 firms. During this period, 3012 and 3005 work on installing STL at oil fields and participate in the development of STP. The network is divided into four structural equivalence groups.

<<< Insert Table 2 about here >>>

Block 1 is a value chain for STL. In this block, I find most of the APL employees and the firms that manufacture parts and do assembly of the STL buoy; all of them participate in discussions of technological solutions. Firms and institutions also provide services for the construction and field installation of STL, including one of the first fields to use STL (BP Harding) and Norsk Hydro that will also use the buoy.

Block 2 consists of APL (including 1004, one of the originators of STL); both STP originators 3005 and 3012 belong to this block. Additionally, block 2 has oil fields and firms involved in installation and operation of oil loading. Block 3 has several firms that deliver supplies to oil fields, and load and transport oil. Finally, block 4 has the STP developers and some firms that represent cooperating partners and prospective users.

<<< Insert Table 3 about here >>>

The reduced block matrix, Table 1, shows that within block densities are highest in block 2, which is also connected to blocks 1 and 4. Block 3 is the least connected block, both within and to other blocks. The nature of the tasks within the blocks are clearly reflected in the reduced block matrix. There is a clear need for coordinating the STL value chain block (1) and the oil fields where the installation is taking place (block 2). The presence of some of the most important people of both APL (1004) and Statoil (3005 and 3012) in block 2 can explain the high within and between block densities of this block. Particularly, there are several connections to block 4 and 1. This shows how closely the development of STP is to STL developers and the future users of this technology.

DISCUSSION AND CONCLUSION

Rigid institutional structures curb creativity. As one proceeds through the layers of nested networks, from the core to the periphery, structures become increasingly fragmented. At the level of the oil industry, the upper layer of the nested network, the firms where these innovations originate are on the fringe. Their knowledge and traditions come from an industry outfitting tankers that participate in buoy loading of oil. Their main customer is a small and newly established oil company. Statoil has few traditions and set paradigms for uploading and processing crude oil. On the contrary Statoil, observing that traditional technologies already failed, participates in other innovations that have revolutionized oil technology. Thus, the upper layer of the nested networks do not contain constraints impeding creative innovations. The mindsets are not restricted. People and firms are open for experiments, they look for progress in fundamental knowledge that can be used to improve technology.

Firm level relations, the second layer of the nested networks, shows that the innovators are well connected to firms and institutions that develop basic knowledge. The position of MCG, Statoil, and Framo Engineering within the nested structures connects them directly to organizations that break fundamental knowledge barriers. The first proposition stated that “people who are embedded in social networks that span several firms and institutions, are more likely than people lacking such connections to be creative innovators.” All originators and their closest collaborators are directly connected to people who provided the three pieces of knowledge that made STL/STP possible. They are examples of the individuals’ networks that are connected into the higher level networks completing the nested layered networks of firms and research institutes.

The second proposition stated that “people who have a career path going through several different firms, are more likely to have interdisciplinary networks than people without such careers.” The originators had central positions in several diverse firms. Their closest collaborators, with whom they discussed these issues, had careers based in even more firms. These close collaborators are crucial assets in mobilizing the necessary knowledge and complementary resources. Without these contacts, the innovations may not have been realized. Building social networks over long careers gave them valuable contacts that were willing to participate in the development of radical new ideas.

The third proposition states: “having careers spanning several firms and projects increases people’s ability to communicate across disciplines.” As expected, the complexity of these technologies and the short development time indicates that people communicated effectively. This again supports the interactions that enter creative processes. In this case interactions proceed through several years starting during the early stages of development of the concepts as well as during the construction and deployment of the technologies.

The fourth proposition states that “the higher the network centrality of actors the more able they are in mobilizing complementary resources.” In both projects, the participants that are key in mobilizing resources all have high network centrality. They not only have short paths to most people in the network. They also know who is connected to whom in the network. These complex innovations required inputs from several discipline. In the early phases of the creation of the concepts, the innovators had an idea about whom to contact to mobilize the necessary knowledge to complete the technologies. They activated the necessary discussion partners so that the necessary expertise could solve the problems of combining cross-disciplinary knowledge.

This case study shows the development of a network structure and the use of social capital in eliciting radical concepts and transforming them into workable technologies. A case study contributes knowledge for further testing, and these propositions should be tested in studies with multiple cases of firms with degrees of successful innovations. Few studies have gone into the history of relations and the detailed development of networks during the development process. Moreover, studies mostly take for granted that young people are most creative. I found, in contrast, immense creativity was only feasible after a lifetime of building networks. These innovations needed complex, interdisciplinary knowledge. Only long careers can establish the interdisciplinary and interorganizational networks that can combine to produce complex technologies. This combinative ability is a kind of creativity that comes with age. By focusing mainly on individuals, our field overlooks the wider social milieu that infuse mature persons with the ability to create and to take advantage of long careers building social networks.

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TABLE 1. Block model of the network in 1990 with four structurally equivalent groups.

Block 1	Block 2	Block 3	Block 4
Framo Engineering	Statoil	Statoil	Framo Engineering
Statoil	DNVC	Norsk Hydro	Statoil
Brd. Johnsen	Marintek	Rasmussen	DNVC
DNVC	SINTEF		MCG
MCG	Scana Staal		Stolt Comex Seaway
Marintek			Yme

TABLE 2. Block model of the network in 1994 with four structurally equivalent groups.[a]

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

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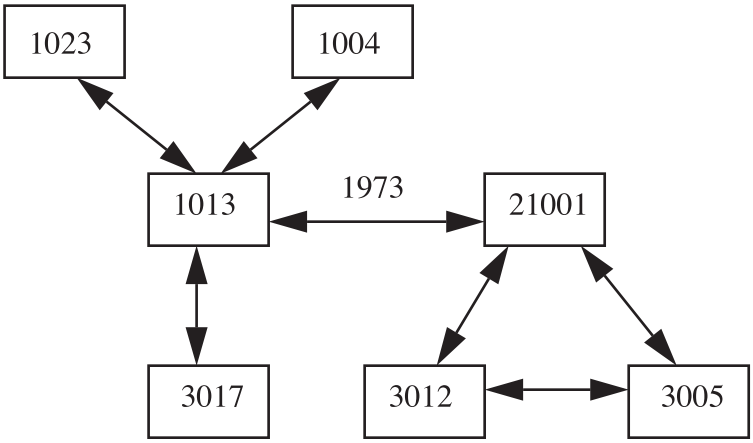
a.The numbers in parenthesis indicate the number of people in each firm

TABLE 3. Block model of the network in 1994 with four structurally equivalent groups. Reduced block matrix for 1994. Overall network density= 0.07
TABLE 4.

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

Numbers are within and between block network densities (number relations present/total no. of possible relations).

FIGURE 1. The social network before 1970



1004 got the idea for STL around 1990/1.

1013 worked with MCG starting in 1990, and with APL from its establishment, he is one of the main coordinators of the STL network

3012 got the idea for STP during work on STL in 1993, discussed it with his partner 3005.

21001 participated in the development of the anchoring models, he connected the two network clusters with 1013 in 1973.