The social structure of leadership and creativity in engineering design teams

1. Introduction

As firms struggle to establish or maintain prosperity in turbulent and competitive environments, creativity becomes increasingly important (De Vanna & Tichy, 1990). Researchers widely agree that creativity is essential for the long-term survival of organizations, since it is the foundation of organizations' innovative potential (e.g., Glynn, 1996; Oldham & Cummings, 1996; Scott & Bruce, 1994; Shalley, 1995; Unsworth, 2001). Indeed, there are very few business functions for which a fair level of creativity is not important. A marketing department is highly dependent on creative thought to generate ways to catch and hold the attention of (potential) customers. In product development much creativity is required in finding novel answers to customers' wants and needs and in discovering technical solutions to bring them into being. Similarly, manufacturing demands creative approaches in devising (more) efficient ways of manufacturing. Distinctive about post-industrial society is the emergence of categories of work in which creativity and intellectual skills are distinguishing features. Creativity is now often at the basis of a company's competitive position since it is the design, development, marketing, and selling of products and services rather than their manufacture which are at the core of the business (Davis & Scase, 2000).

Accordingly, increasing attention has been given to understanding creativity in particular in the last decade (Cummings & Oldham, 1997; Ford, 1996; Kratzer et al., 2004; Leenders et al., 2003; Woodman et al., 1993). Like other crucial organizational outcome, creativity and innovation stem not only from overall firm strategy and access to resources, more fundamentally, from the minds of the individual employees who, with others, carry out the work of the organization every day (Amabile et al., 2004). The extent to which they will produce creative – novel and useful – ideas during their everyday work depends not only on their individual characteristic, but also on the work environment around them (Amabile et al., 2004; Perry-Smith & Shalley, 2003; Reiter-Palmon & Illies, 2004). In contemporary knowledge-work-intensiv environments as engineering design teams face, most projects are done by teams of professionals striving to be creative in developing new products, new services, or new processes (Griffin, 1997; Van Engelen et al., 2001). Of all of the forces that impinge on people's daily experience of the work environment in teams, one of the most immediate and potent is likely to be the social process in which the team members are embedded (Leenders et al., 2003; Perry-Smith and Shalley, 2003). In all three prominent creativity models (Amabile, 1988; Ford, 1996; Woodman et al., 1993), the social processes are important antecedents to creativity.

This more social view of creativity is supported by a limited but growing collection of empirical evidence. Since the core product of creativity is new knowledge, and new knowledge can only be created when existing bases of knowledge are disseminated through interaction between specialists with varying areas of expertise, creativity is couched in communication networks. The association between knowledge transfer and communication networks is widely confirmed in the scientific literature (Hansen, 1999; Ingram & Roberts, 2000; Reagans & Zuckerman, 2001; Uzzi, 1996; Tsai, 2001). Communication is the means through which a team stores and disseminates information and more frequent communication makes cross-fertilization of ideas increasingly likely (Mumford and Gustafson, 1988). Creativity is therefore largely shaped by the coordinated communication among the members of the team (Leenders et al., 2003). Leadership of these teams or those 'local leaders' who coordinate the member's access to knowledge and information navigate these communication networks (Amabile et al., 2004). Surprisingly, the navigating role of leadership has not generally been treated as a particular important influence on creativity (Mumford et al., 2002), despite the likely impact of leadership on the work environment (Shalley & Gilson, 2004), and the demonstrated impact of the work environment on creativity (Amabile et al, 1996; Leenders et al., 2003; Mumford et al., 2002). In addition, with the emergence of more matrix-like organizations the lightweight team leader role has continuously been redefined toward one of more importance (Norrgren & Schaller, 1999). In particular, engineering design teams are increasingly autonomous units in which leadership is a decisive factor (Crawford & Di Benedetto, 2000).

In this study we focus on the position of team leaders within the internal communication networks and their external contacts and how these positions do impact the creativity of engineering design teams. Our main goal is to build a conceptual model of how the leader position in different internal and external communication networks affects the creativity of engineering design teams. In order to explore this issue we gathered data in 39 engineering design teams engaged in space industry around the globe. In the first part of the paper we review the existing literature on leadership and creativity and clarify our concepts of leader position and communication networks. In this part we introduce the balance between a periphery and central position of team leaders as the most important positional characteristic and distinguish three communication networks, the work-flow network, the problem-solving network, and the awareness network. Thereafter, we formulate hypotheses about the relationship between the leader's position in the different internal and external communication networks and creativity. In the second part of the paper we explain our empirical study and present the results. Finally we discuss the results, draw academic and practical conclusions, and built upon these conclusions a conceptual model of how to lead engineering design teams toward creativity. The central implication of our findings is that in order to navigate engineering design teams toward creativity leaders have to smartly limit their communicational involvement within internal communication networks and to concentrate on the role of gatekeepers linking the external and internal communication networks.

2. The balance between periphery and central leader positions and creativity

The literature linking leadership to group performance is scant (Kim & Yukl, 1995; Amabile et al., 2004), and the literature investigating the impact of leadership on creativity is even smaller. A handful of prior studies have found positive links between creativity and some specific team leader behaviors, such as, serving as an ambassador for the team within the organization (Ancona & Caldwell, 1992), focusing on work-related rather than administrative communications (Katz & Tushman, 1979), providing various forms of assistance and support to the team's work (Amabile et al., 2004; Madjar et al., 2002; Shalley & Gilson, 2004; Tierney & Farmer, 2004; Zhou & George, 2003), and providing general supervision (Barnowe, 1975). According to leader-member exchange theory (Gerstner & Day, 1997) each employee establishes a social exchange relationship with his or her supervisors, and the quality of this leader-member exchange is generally found to be positively related to job performance (Janssen & Van Yperen, 2004). Put somewhat differently, leaders can offer a valuable input to team processes and coordinate the dissemination of this input to each single team member (Day et al., 2004). In this way team leaders link the external and the internal communication networks. Both the external and internal communication networks are recognized as extremely critical for innovation endeavors (O'Connor & McDermott, 2004). When these networks are critical to innovation outcomes the position of the leader then is inherently also critical, since team leaders are by description the most important network players.

In the network literature a number of different network positions is described and conceptualized. The balance between a central position and a periphery position is among the most fundamental concepts.

Insert Figure 1 about here

When looking at the communication network at figure 1 the position of leader A is highly central, since he/she is involved in many (strong) communicational linkages with his/her subordinates, whereas leader position B without any communicational involvement is most periphery. Dating back to the MIT studies conducted by Bavelas (1950) and Leavitt (1951) in the late 1940's, researchers have found the balance between periphery and central network positions to be associated with social power and structural influence. Mullen and Johnson (1991) conclude that holding a central position is a significant and independent predictor of leadership. In this study, therefore, we apply the balance between periphery and central positions since it focuses on social power and structural influence which gradually arises from holding a more central position in communication networks (Bacharach & Lawler, 1980; Kratzer, 2001). Holding a central position within a communication network implies high degrees of access and control over information and knowledge.

Research investigating intra-organizational social networks has found that central network positions and the opportunity to connect effectively to others in the organization provide access to knowledge and information and improve the ability to innovate (Hansen, 2002; Tsai, 2001). This research, however, concentrates on the business unit level and does not capture the intensity and richness of interpersonal communication networks (Oliver & Liebeskind, 1998). In addition, most network studies researchers have traditionally focused on the structure of networks (Burt, 1992; Granovetter, 1973; Sparrow et al., 2001) and paid less attention to theoretically important features of the ties, or communication linkages, within these networks (Adler & Kwon, 2002; Higgens & Kram, 2001; Monge & Contractor, 2001). Considering the range of communication, however, it is reasonable to anticipate that certain ties might yield better or more or other relevant information than others (Cross & Cummings, 2004). Network structure alone can not capture the effects that such ties have on knowledge and information acquisition and distribution and creativity in knowledge-intensive work environments. If reviewing possible and tractable transactional contents of communication in innovative settings, a very many-sided picture appears at the first glance. For example, in a study of Norling (1996) content networks, situational networks and process or workflow networks are distinguished. While in another study of Morelli et. al. (1995) within R&D units, three types of communication are discerned: first, coordination type, second, knowledge type, and finally, inspiration type. Smith-Doerr et al. (2004) distinguish instrumental, expressive, technical advice, and organizational advice networks in a study of narratives of R&D team members. All these different distinctions, however, show similarities. First, networks that describe the exchange of certain goods, services, in engineering design teams more often blueprints, drawings etc., which are differently labeled in work-flow, coordination type, or instrumental networks. The second common type of networks describe the exchange of different information or knowledge, such as problem-solving (e.g., Kratzer, 2001), knowledge type, technical/organizational, and content networks. And third, another dimension attempts to capture the non work-related side of communication as situational, inspiration or expressive networks. In a very recent work of Cross and Cummings (2004) this type of network is labeled awareness network, describing the network of knowledge team members have about each other. In particular in a knowledge-intensive environment it is extremely important to know where are the sources of expertise, knowledge, and information. In addition, when taking a closer look at the leadership tasks the derivation of the three network contents seems logical. The first major task of team leaders is the management of the work processes in teams. The execution of this task can be described in the work-flow network. Since research and development requires interaction team leaders have to make sure that this interaction takes place resulting in an exchange of knowledge and information. The fulfillment of this task can be traced when investigating the problem-solving network of teams. Interaction may be a very time consuming activity, therefore, it is important to interact with the right person at the right time. Subsequently, the knowledge who has to interact with whom and when is essential for team leaders to navigate the team forward. This knowledge is established in the awareness network of the team. Accordingly, in our study we apply these three network types as work-flow network, problem-solving network, describing the exchange of information within the team, and awareness network. Next to investigating these team internal networks we examine the leader position within the external information network labeled as boundary spanning capacity. The information network is similar to the problem-solving network, but in order to distinguish these two networks we labeled them differently. In addition the information network is operationalized in less detail since it addresses the flow of information and knowledge between teams and not between team members. The boundary spanning capacity refers to the number of other engineering design teams a team leader is tapping for information.

2.1. Work-flow network: Leader position and creativity

Engineering design team members have no choice but to have some kind of work-related exchange of outputs and inputs. This exchange structure can be differently strong and can be classified in independent, sequential, mutual or pooled exchange according to Thompson (1969). In a recent study Kratzer et al. (2005) indicate that the coordination of the work-flow network can be used as managerial tool to inspire creativity in innovation teams. There are two components that mainly determine this structure. First, the decomposition of the task at hand and the resulting interfaces which require team member exchanges. And second, the coordinating hand of the team leader who can connect or disconnect team members for managerial reasons. In innovation trajectories this structure inevitable changes and adapts to the shifting challenges and tasks. The role of team leaders in work-flow networks is twofold. Team leaders as coordinators monitor the work-flow and change or intervene when the situation does require it. On the other hand, team leaders themselves have to be so much involved in the work-flow to be able to evaluate the work progress and to navigate the team. This twofold role has certain consequences for the creativity of the team. Team leaders who are strongly involved in the work-flow network easily get overloaded with knowledge and decision needs and impede creativity, since team members may get the necessary input delayed or not at all. In addition, a strong central position within the work-flow network may discourage team members to find novel solutions by centralizing the responsibilities of work-related exchanges. On the other hand, without the monitoring and navigating execution of the manager’s work the team may shift away from seeking creative solutions. This phenomenon may occur when communication problems arise or certain members free-ride on the contributions of others. This development may go so far that the set standards or requirements are lowered by the team members themselves resulting in poorly creative solutions.

Hypothesis 1: Very periphery and very central positions of the team leaders within the work-flow network impede the creativity of engineering design teams.

2.2. Problem-solving network: Leader position and creativity

Creativity in knowledge-intensive environments is, to some degree, a product of obtaining the right knowledge and information at the right time to solve novel, challenging problems. A high team leader centrality in information sharing is commonly believed to inhibit creativity (Leenders et al., 2003). Team leaders who dominate discussions and searches for innovative solutions are prone to information overload. The more innovative and complex the new product tasks, the more different bases of expertise are required. Especially in highly technological areas, no single team member, regardless of tenure, status, or skill, can have enough knowledge to oversee all areas of expertise proficiently. The team leader will likely impede engineering design team creativity by wasting time and distorting the problem solving process. Team members may not, or too late, receive the information necessary for their part of the task. This may require them to throw away previous work in light of this 'new' information and start over again. In addition, when communication is less centralized, accountability for the team's results (both in terms of end results, intermediate results, and milestones) becomes more evenly distributed across team members. Every member then becomes engaged in the process and in finding creative solutions to the problems at hand. Moreover, the presence of highly central team members reduces the autonomy of non-central individuals. This autonomy is instrumental to creative achievement (Amabile, 1983).

Hypothesis 2: The more central the position of the team leader within the problem-solving network the lower is the creativity of engineering design teams.

2.3. Awareness network: Leader position and creativity

In knowledge-intensive work, work-flow and problem-solving networks are often dynamic, and they shift when new projects demand different kinds of information and expertise. As new problems or opportunities arise, the set of relationships one is currently tapping for information can be less helpful than different group members one is not aware of and able to turn to for information relevant to new tasks. A network can supplement a person's ability to respond well to new challenges when that person knows whom to seek out for knowledge and information relevant to a new project. Thus, team leaders that are more aware of team member's expertise should be more likely to link the right people at the right time when those are presented with unique challenges. According to Borgatti and Cross (2003) one's awareness of another's expertise, or the extent to which one person knows what another person knows, is associated with the likelihood of seeking information from that person. In engineering design team, however, very specialized expertise is scattered within the team that no member can possibly oversee all area's of expertise of his or her colleagues. Team leaders, however, who are aware of the distribution of knowledge and expertise within the team, can coordinate the team in a way that the right members at the right time exchange their knowledge and information. As Cross and Cummings (2004) indicate team members with greater awareness of disparate expertise within a network improves one's ability to respond appropriately when new challenges demand different knowledge.

Hypothesis 3: The more central the position of the team leader within the awareness network the higher is the creativity of engineering design teams.

2.4. Boundary spanning capacity and creativity

As indicated earlier team leaders have the ascribed role of gatekeepers that link the external and internal communication networks. Thus, leaders can stay central within the internal networks but also maintain a number of contacts to other engineering design teams in the same organization. The degree to which the team leaders are linked to other teams describes their external centrality or boundary spanning capacity. In our study we restrict boundary spanning to the information network. Boundary spanning has long been known to influence how information enters organizations (Tushman, 1977; Tushman & Katz, 1980). For example, ties crossing boundaries are associated with adoption of less normative strategies (Geletkanycz & Hambrick, 1997), acquisition of competitive capabilities (McEvily & Zaheer, 1999), and product innovation (Hargadon & Sutton, 1997). Early work demonstrated the critical role of gatekeepers crossing technical boundaries (Allen, 1977). More recently, research has demonstrated the importance of ties crossing departments or functional boundaries for effective knowledge transfer within organizations (Hansen, 2002; Szulanski, 1996; Tsai, 2001). Team leaders who stay central in the external information network have a high boundary spanning capacity, since they can gather demanded information easily in their network. Subsequently, a high boundary spanning capacity enables team leaders to provide the engineering team members with the right information and knowledge at the right time.

Hypothesis 4: The more central the position of the team leader within the external information network (or the higher the boundary spanning capacity) the higher is the creativity of engineering design teams.

3. Methods

3.1. Study setting

To explore the social structure of leadership and creativity in engineering design team we collected data in 39 engineering design teams with 321 team members engaged in space industry around the globe in 17 countries. All engineering design teams are part of three large instrument consortia coordinated by the European Space Agency (ESA). All three consortia are engaged in the development of telescopes and are compareable in terms of budget, time-lines, and complexity. More in detail, for all three consortia the scheduled budgets are higher than $ 250.000.000, they have a scheduled tenure from 11 to 14 years, and all three face a very high complexity by developing completely new technical solutions. The three large instrument consortia employ 71 engineering design teams. Many team leaders, however, are responsible for more than one engineering design team, so we selected the teams that have different team leaders to prevent theoretical as well as analytical problems. In order to do so we randomly selected one team for each team leader who is responsible for more than one team. The teams mainly employ male members, the percentage of women is neglectible with less than 3%. The teams are on average 4.5 years old and accept of very few cases they employed the same team members throughout this time. So, the social structure of the teams can be described as very stable. Most team members own a master degree 56%, 34% of the team members have a bachelor degree, and 10% a Ph.D.

For gathering the required data we used semi-structured interviews and questionnaires. All 39 team leaders were interviewed and completed a questionnaire resulting in a response rate of 100%. All team members were asked to fill in a questionnaire resulting in a response rate of 72%. The team leaders were approached during formal team meetings and the team member questionnaires were send by post. The individual identification of the interview and questionnaire data was removed once the data were entered, such that all information was maintained but information about the identity of the individuals was invalidated. In this way the survey was held completely anonymous. In all engineering design teams preliminary interviews with the project management, observation, and existing documentation confirmed that the work in each setting was highly knowledge intensive and collaborative. Moreover, the data collected were widely confirmed by this additional information.

3.2. Defining and measuring the creativity of engineering design teams

There are many views of creativity. Amabile (1988) argues that creativity is exhibited when a product or service is generated that is both novel and useful with respect to the firm. Woodman, Sawyer, & Griffin (1993: 293) contend that creativity refers to ‘the creation of a valuable, useful new product, service, idea, procedure, or process by individuals working together in a complex social system.’ King and Anderson (1990: 82) proposed that creativity at the team level explicitly incorporates the interpersonal discussion among team members. In the present research, we build on Woodman, Sawyer, & Griffin (1993) and take King and Anderson's proposition as a central theme in our study.

Much of the research on creativity has been conducted in experimental settings in behavioral laboratories, often with students and children as subjects. Although some of these experiments are set up to mirror organizational situations (e.g., Amabile, 1996; Carson & Carson, 1993; Hackman & Oldham, 1980), they can hardly capture the creative processes that occur in real organizational groups where the project management structure is composed of multifunctional teams (Drazin et al.,1999) and are too large to be experimentally viable. Moreover, the engineering design process is characterized by long time horizons: creative solutions to sub-problems may not turn out viable after solutions to other sub-problems have been devised (which may occur only much later in the project) and the separation in time between the creative act and its evaluation is often long. In addition, the creative task of engineering design teams is typically more multifaceted and intricate than research settings allow.

Measuring creativity, therefore, is notoriously difficult. In the lion share of creativity studies, creativity is measured in either of two ways. First, by the performance of (groups of) individuals on standardized creativity tests—constructed and scored similarly to tests of verbal and mathematical intelligence. Alternatively, a second group of measures entails the rating of actual products in response to open-ended instructions. Rating is then performed by outside experts. These measures, however, are not appropriate for our research. Since we had no outside experts available to assess the teams' creativity, we asked inside experts with—for most of them—a long experience in the field: the team leaders and the members themselves. On a 7-point scale we asked the team leaders and members to rate the team's creativity using the following items:

1. How would you estimate the newness and originality of the solutions your team finds to problems? (7-point scale from 1-not new to 7-very knew)
2. How would you estimate the number of possible solutions your team develops to solve problems? (7-point scale from 1-not high to 7-very high)
3. How would you estimate the number of possible solutions your team takes into consideration in order to solve problems? (7-point scale from 1-not high to 7-very high)

In order to have one measure of creativity we combined the three items into one scale of creativity reaching from 1 – very low to 7 – very high. The reliability of this scale was tested and is with Cronbach's alpha 0.82 satisfactory high.

The measure for team level creativity thus derives from the assessment by its leaders and members; in this sense, it is a quasi self-report measure. Self-report measures are often criticized, mainly through the argument that some people are unable to report their performance accurately, due to reasons of poor introspection (e.g., Locke et al., 1988). Since we asked team members and leaders to evaluate their team's creativity rather than their own individual creativity, the effect should be much smaller in our data than in the situation in which individuals are asked to assess their own individual creativity. Moreover, in his well-known study of engineering design team's success factors, Cooper (1981) achieved accuracy levels of over eighty percent asking team members and leaders to assess their projects ex-post.

Finally, there is evidence that self-ratings correlate highly with more 'objective' measures in cases when anonymity is promised. In particular, Heneman (1974) found that self-report measures had less restriction of range and leniency than the purportedly more objective supervisor ratings. He suggested that this reflected the fact that self-reports were obtained explicitly for research purposes and were not to be used for evaluatory or other organizational purposes. The same holds for our measure, since we promised that the responses would not be shared with management. They can thus be expected to paint a reliable picture of actual team level creativity.

3.3. Measuring the communication networks

In the survey, a full roster of team members (including the team leaders) was used for each engineering design team. Each team leader and member was asked to report the communication with all other team members in the roster. The result of this question is a valued asymmetric matrix for each engineering design team with values 0 = no (or less than monthly) communication; 1 = (at least) monthly communication, 2 = (at least) weekly communication. For the external communication we used the same scale. The question was addressed to the team leaders by presenting them a full roster of all involved engineering design teams within the relevant instrument consortia. In this way we created a valued asymmetric matrix with values 0 = no (or less than) monthly communication; 1 = (at least) monthly communication and 2 = (at least) weekly communication. This procedure is typical for the way in which communication network data are collected (e.g. Leenders, 2003).

The separate networks were addressed using the following questions:

On average, how often do you interact with other members within your team about the following aspects?

Work-flow network	*The exchange of facts (e.g. designs, manufacturing drawings, models or test data).*
Problem-solving network	*The communication involving the discussion, innovation, or evaluation of new ideas or approaches to technical problems; technical or scientific help or advice; mutual use as 'sounding board' for ideas; distribution of scientific or technical information stemming from outside of the team.*
Awareness network	*The exchange of information about the persons in the organization (e.g., knowledge about who has what role or task in the project or who has the formal authority to take certain decisions).*

The external information network:

On average, how often do you exchange information and knowledge with members of other engineering design teams within your instrument consortia?

3.4. Defining and measuring the balance of periphery and central positions within communication networks

Among the proposed measures of positional centrality, degree centrality is the simplest and most straightforward (Zemljič & Hlebec, 2005). Degree centrality is based on the number of units directly connected to the unit under scrutiny. The definition of actor centrality is that the most central actor must be the most active, in the sense that this actor has the largest number of ties to other actors in the network (Freeman, 1979). In this way it measures the balance between having a peripheral position or a low degree centrality or having a central position or a high degree centrality. The measure is focused on the level of communication activity for internal communication networks on the intra-team or individual level and for the external information network on the intra-team or unit level. In a directed network there are two distinct degree centralities, i.e., in-degree (choices received) and out-degree (choices made). The distinction between out-links and in-links is particularly important in some cases since their interpretation could not be the same. In our study, however, there is no meaningful distinction between out-links and in-links, since two connected team members communicate regardless which team member sends or which one receives information (Barnowe, 1975). This assumption is supported by empirical evidence showing that two-way interaction is more frequent in engineering design teams than one-way information flows (Morelli et al., 1995). We also executed the analyses separately for the in-degrees and out-degrees and did not find any differences in the results. In addition the reciprocity of indications in both matrixes is highly significant ($\alpha < 0.001$), so that we decided to symmetrize the matrixes. Symmetrized matrices also increase the robustness of the data. The analyses presented are based on the symmetrized matrixes.

For the external information network we used the out-degree answers of the team leaders. We also considered other measures of centrality, i.e. betweenness, degree (Freeman, 1979) or eigenvector (Bonanchich, 1987), but choose degree for parsimony. Moreover, the position of the team leader does not change if alternative measures are used. For computing the degree centrality we used UCINET 5.1. (Borgatti et al., 1999).

3.5. Analyzing the data

In this research, we are interested in the factors that explain the relationship between leadership and creativity in engineering design teams. In engineering design team settings where the object of creativity is complex and requires skills from multiple bases of expertise, it is difficult to separate out individual- from team-level contributions. Teams also go through stages that mirror the processes of individuals—that is, developing criteria, generating alternatives, modifying those alternatives, and amplifying and extending original ideas. Individuals and teams participate in creative processes in an iterative fashion. In the present article we follow the suggestion of Drazin et al. (1999) and Klein et al. (1994) and assume individuals to act homogeneously within the teams as they engage in creative behavior. In other words, we assume there is no need to incorporate individual level variables, such as functional background, education, and tenure into our analysis of team level creative performance. We therefore limit ourselves to incorporating team level aggregates into our analysis. In order to statistically justify this aggregation, a one-way analysis of variance was conducted to determine if there was greater variability between teams than within teams on team creativity ratings. The analysis of variance supported the appropriateness of the aggregation (F=3.13, p<.000). Prior to aggregating team members' evaluations, inter-rater agreement on the team's creativity was calculated by averaging the inter-rater reliability (IRR) score suggested by James et al. (1984). The IRR was .72, justifying the use of the arithmetic mean as a team score.

For testing the hypotheses we the executed multiple regressions and entered the independent variables stepwise into the regression models 1 to 4. We tested for violations of multiconliniarity by checking the VIF (Variable inflation factor) and CI (Condition index) and the distribution of residuals. These examinations did not reveal any violation. Testing Hypothesis 1 requires a polynomial effect to be included in the regression. However, the high correlation between the square of leader centrality of the work-flow network itself would introduce problems of multicollinearity into the analysis. We solved this by centering leader centrality of the work-flow network by subtracting the overall mean from it. The squared value incorporated into the regression analyses is the squared value of this centered variable.

Insert Table 1 about here

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4. Results

As table 1 shows the distribution of involvement in the different internal communication networks varies. Team leaders spend most time in communicating about problem-solving issues, followed by the involvement in the work-flow network as the mean values indicate. The least time of team leaders is devoted to be active in the awareness network. This is an interesting result of its one because it shows how much leaders involve in work-related activities. The leader boundary spanning capacity can not be compared to the other networks, since it is measures on a valued base. A second immediate result is that the correlations between the three team-internal networks are not higher than 0.44. This implicates that we indeed measured three distinct networks.

Insert Table 2 about here

In table 2 the regression model about the leader centrality within the work-flow network and creativity is illustrated. As it is shown the relationship is indeed inversely U-shaped as proposed in hypothesis 1 and the result is statistically significant. Regression model 2 in table 2 refers to the impact of leader centrality within the problem-solving network and creativity. The regression model 2 confirms statistically significant the proposed negative effect of leader centrality within the problem-solving network and creativity. That allows verifying hypothesis 2. In addition, there is a statistical significant improvement of model 2 in comparison to model 1. The explained variance is with 31% interestingly high. Regression model 3 addresses the relationship between leader centrality within the awareness network and creativity. The formulated hypothesis 3 proposed a positive relationship. The results do not allow to verify this hypothesis since the regression coefficient is positive but not statistically significant. Moreover there is no statistical significant improvement from regression model 2 to regression model 3. The relationship between the boundary spanning capacity of the team leader and team creativity is tested in regression model 4. The boundary spanning capacity of the team leader positively relates statistically significant to creativity as proposed in hypothesis 4. The inclusion of boundary spanning capacity of the team leader improves the quality of the regression statistically significant. The explained variance of regression model 4 is with 42% considerably high.

The model 3 shows that hypothesis 3 can not be confirmed. It may be that team members are limited in their autonomy, when the team leader is too central. In addition, the search process of information may be a creativity stimulating process by its own. In order to statistically explore these thoughts indicating a quadratic relationship we entered the quadratic term of the leader centrality within the awareness network into the regression. Also this quadratic variable was centered by subtracting the overall mean from it to avoid problems of multicollinearity. The results are displayed in table 3. The regression model 5 justifies this exploration since the relationship between the centrality of the team leader within the awareness network and creativity is indeed statistically significant inversely U-shaped. This statistically significance, however, only reaches the 10% level of taking the risk of making a mistake of type I. The regression model is statistically significant improved by entering the quadratic term of leader centrality within the awareness network and explains 47% of the variance of creativity.

Insert Table 3 about here

In summarizing the results it can be stated that the centrality of the team leader in different networks impacts the creativity of engineering design teams. In detail, the results confirm hypothesis 1 by showing an inversely U-shaped relationship between the leader centrality in the work-flow network and creativity. Also the proposed relationship between the negative effect of leader centrality within the problem-solving network and creativity in hypothesis 2 is confirmed. Hypothesis 3, which proposed a positive relationship between leader centrality within the awareness network and engineering design team creativity is not confirmed. In contrast, when testing this relationship an inversely U-shaped relationship turned out. Finally, the boundary spanning capacity of the team leader strongly positive relates to the engineering design team creativity.

5. Discussion and implications

In the last decade creativity was realized as one of the most important factors to secure the prosperity of company's existence. Perhaps the 'creating-creative' organization of the future is one that will integrate and move beyond the promises of the models of the new organization for the third millennium such as the learning organization (Sage, 1990) or the knowledge-generating company (Nonaka & Takeuchi, 1995). Creativity has long been studied on the individual level by looking at certain personal traits that generate or impede creativity. Since the path breaking work of Amabile (1988), Ford (1996), and Woodman et al. (1993) we know that creativity is more than an individual characteristic. The research investigating creativity increasingly came behind factors in the environment of individuals that stimulate or discourage creativity. The foremost mentioned factor is the social process in which individuals are embedded. Social processes can be studied and mapped by looking at the communication networks. Since communication networks exemplify the flow of knowledge and information they are one of the most important objects to study in order to unravel the secrets of creativity. In communication networks of teams the team leader has by ascription the most important position. In particular engineering design teams work increasingly autonomous so that the team leader has become even more vital to the functioning of the group. In the 60th team leaders had hardly autonomous responsibilities. This situation changed this throughout time so that nowadays team leaders, especially of larger projects, own the majority of responsibilities and report directly to the higher management. It is surprising that hardly anyone investigated this position within different communication networks and its impact on the creativity of teams. Exactly this issue was investigated in engineering design team who are at the forefront of creative challenges. In detail, we examined the intra-team centrality of leaders in three networks, the work-flow network, the problem-solving network, and the awareness network. In addition, we looked at the external activity of the leader in the information network. The results suggest that the different positioning of engineering team leaders in these networks can enhance or impede creativity.

As the analyses show the relationship between leader centrality in the work-flow network and creativity is inversely U-shaped. Translated into managerial terms this means leaders who are strongly or hardly involved in the work-flow processes negatively affect the creativity of their group. There may be several explanations for this finding. When leaders are strongly involved in the work-flow they easily may get overloaded with knowledge, information, and decision needs. This, in turn, leads to two effects that negatively impact creativity. First, the responsibilities are centralized discouraging team members, and the provision with knowledge and information has in the team leader a hampering bottleneck. On the contrary, when team leaders are hardly or not at all involved in the work-flow processes they can not monitor communication problems or situation, in which the team does not properly adapt to the tasks at hand.

The centrality of the team leader in the problem-solving network and creativity negatively relate to each other. This result suggests that leaders who involve in the problem-solving process of the engineering design team are a disturbing factor that impedes creativity. Engineering team members seemingly need autonomy, their own responsibilities, and individual freedom to find novel and useful solutions. As research shows also the overall problem-solving communication of a team can negatively impact creativity. Certainly communication between team members is essential to exchange the required knowledge and information, but frequent problem-solving communication on a day level was found to impede creativity (Kratzer, 2004). Research in brainstorming groups confirms this result, people create more and more useful ideas to problems when they are working alone rather than in a group (Nijstad, 2001). In addition, also in brainstorming groups the communication dominating persons are found to negatively influence the search for ideas (Nijstad, 2001). Subsequently, leaders who do not dominate the problem-solving process are stimulators for creativity.

The relationship between centrality in the awareness network and creativity is inversely U-shaped. This result is in contrast to the hypothesized positive effect. Seemingly, leaders who are to strongly involved in a network containing knowledge about others impede the creative process of engineering design teams. This result may be explained with the arguments mentioned before. It may be that team members also, by searching the right information and knowledge at the right time, need to some degree autonomy and the responsibility to do so of their own. Maybe, the creative searching process for information and knowledge generates the framework and general ideas how to solve problems, since searching involves the framing of a certain problem at hand. In other words, before team members can search for certain information and knowledge they have to decide about what and where to search. On the other hand side, the result also indicates that team leaders should be involved in this process to some degree. In some situations the search process of team members may not be successful or results in insufficient information and knowledge. In this situations team leaders can intervene and link the information searcher to the right information provider. In addition, when team leaders are involved in the awareness network to some degree they are able to monitor possible understanding problems that may occur in multidisciplinary teams.

The analysis of the relationship between the boundary spanning capacity of the team leader and creativity is positive as expected in the hypothesis. This result confirms earlier research on this topic (Allen, 1977; Hansen, 2002; Szulanski, 1996; Tsai, 2001). Seemingly, team leaders who have stable and continue contacts to other organizational units are better able to provide their team with the required input. This result is not surprising, since in highly specialized and knowledge-intensive work environments the required information and knowledge mostly is distributed around more units. The result also indicates that team leaders have to provide about certain communication skills to understand, to select, and to translate the information and knowledge at hand to their own team.

Insert Table 4 about here

The results confirm that leadership plays an important role of understanding the secrets of creativity. The position of the team leader in engineering design team propels creativity when it is moderately centralized in the work-flow network, decentralized in the problem-solving network, moderately centralized in the awareness network, and centralized in the external information network. The results and managerial implications are summarized in figure 2.

6. Conclusions

The postulation that not only personal characteristics, but also environmental factors impact the creativity of teams is confirmed and one empirical finding richer with this study. It can be concluded that different network positions in different networks of team leaders affect the creativity of engineering design teams. The results show positive, inversely U-shaped, and negative relationships. In this analyses it turned out that degree centrality is a powerful measure to study leadership. In addition, the three studied communication networks are distinguishable flows of information and knowledge in engineering design teams. These findings allow drawing two additional conclusions. First, the analysis of social networks is a powerful tool in explaining environmental effects on creativity. Second, there are different flows of information and knowledge in engineering design teams, and each flow has its own characteristic and effect on creativity. In addition, the choice to investigate the three distinctive networks increases the validity of the results found. In managerial terms one implicit conclusion may be drawn. The study indicates not the leaders who are strongly involved in the internal networks stimulate teams towards creativity, but the leaders who are able to gather the necessary information and knowledge outside the team and to smartly distribute it within the team. The choice of promoting team members to team leaders, therefore, should be based on managerial capabilities rather than on professional expertise.

Since our study has its restrictions, research should go on in investigating the relationship of leadership and creativity using the explaining power of social networks and distinguishing different flows of information and knowledge. Future research should concentrate on larger dataset that allow to include more variables in the analyses, such as possible cultural differences, different branches, in which engineering design teams are engaged, company sizes etc.. We are partly going in this direction by including another large instrument consortium in our research. The second suggestion for future research is to study data in a longitudinal setting. Social networks are dynamical systems that may change over time, in particular when a social network just has been established. Moreover, the process of research and development itself refers to a changing structure of tasks and responsibilities throughout time. The networks in the presented study have a tenure of 6 to 7 years, so it can be expected that they are stable. Still, having a longitudinal setting allows to investigate the establishment of engineering design teams, the dynamical way throughout the innovation cycle and subsequently to draw causal conclusions in a much stronger way.

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Figure 1: Central and periphery positions of engineering design team leaders

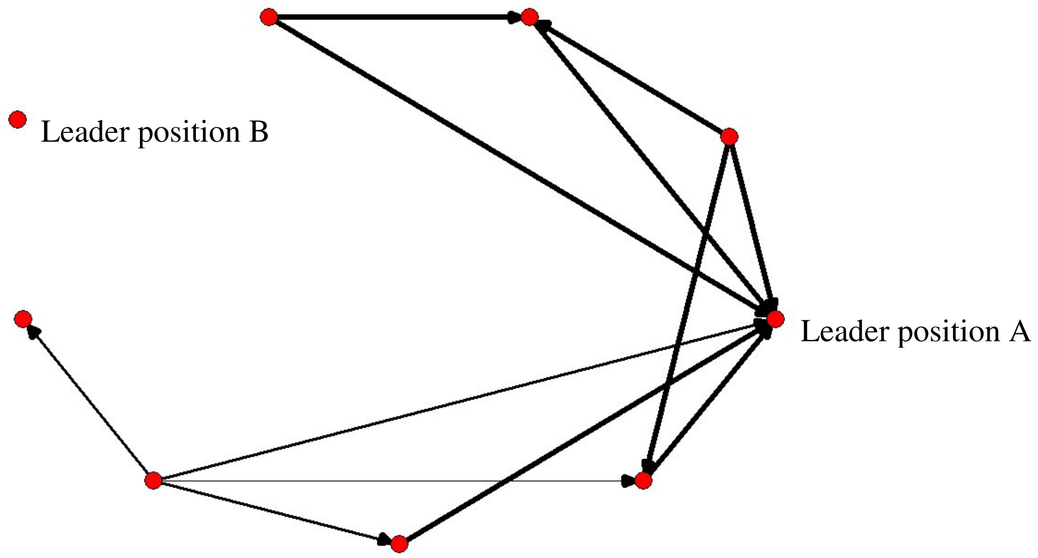


Table 1: Descreptives and Correlations (n=39)

Variables	SD	Mean	1	2	3	4
1. Creativity	0.97	5.34	-	-	-	-
2. Leader centrality work-flow network	0.26	0.57	.45*	-	-	-
3. Leader centrality problem-solving network	0.18	0.67	-.47*	.08	-	-
4. Leader centrality awareness network	0.30	0.37	.09	.44*	.26	-
5. Leader boundary spanning capacity	0.33	0.47	.46*	.27	.14	.40

* significant at * $p < 0.05$

Table 2: Regression results for team creativity (n=39)[a]

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	5.45**(.63)	5.12**(.57)	4.95**(.54)	4.92**(.53)
Leader centrality work-flow network	3.34**(.65)	3.12**(.59)	3.01**(.58)	2.98**(.55)
Leader centrality work-flow network squared	*-4.12**(1.23)*	*-4.23**(1.12)*	*-4.20**(1.11)*	*-4.02**(1.12)*
Leader centrality problem-solving network		-2.87**(.76)	-2.67**(.78)	-2.54**(.75)
Leader centrality awareness network			-1.02(.67)	1.07(.65)
Leader boundary spanning capacity				5.23**(.87)
Adjusted R^2	.21	.31	.32	.42
Significance of R^2 change		.000	.434	.000

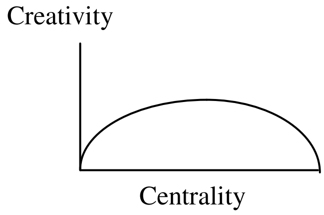
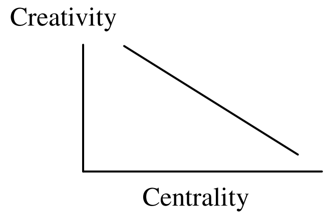
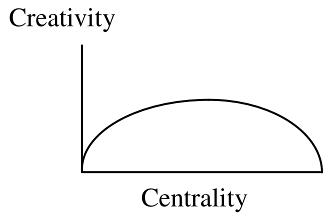
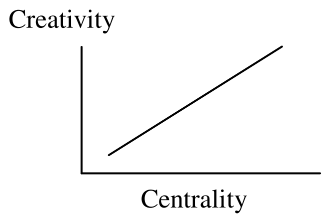
[a]. Unstandardized coefficients are shown (standard errors in parentheses). Two-tailed tests are reported; * $p < .10$, ** $p < .05$.

Table 3: Regression results for team creativity (n=39)[a]

Variables	Model 4	Model 5
Intercept	4.92**(.53)	4.87**(.52)
Leader centrality work-flow network	2.98**(.55)	2.92**(.53)
Leader centrality work-flow network^2	*-4.02**(1.12)*	*-3.56**(1.03)*
Leader centrality problem-solving network	-2.54**(.75)	-2.35**(.65)
Leader centrality awareness network		1.01*(.63)
Leader centrality awareness network^2	*1.07(.65)*	*-2.71*(1.54)*
Leader boundary spanning capacity	5.23**(.87)	5.18**(.81)
Adjusted R^2	.42	.47
Significance of R^2 change		.000

[a]. Unstandardized coefficients are shown (standard errors in parentheses). Two-tailed tests are reported; * p < .10, ** *p* < .05.

Table 4: The social structure of leadership and creativity: Managerial implication

Network property	Relationship between leader centrality and creativity	Managerial implications
Work-flow		The involvement in work-related exchanges should be moderate to a level where leaders can assess the processes, evaluate outcomes, and intervene when necessary.
Problem-solving		The involvement in the problem-solving process of the team members should strictly be kept to a minimum.
Awareness		The involvement in the awareness network should be moderate to a level where leaders can monitor information flows and navigate them when required.
Information: Boundary spanning capacity		Leaders should invest in external networks to provide their own team with all access to knowledge and information possible to fulfill the tasks.