Individual Centrality and Performance in Virtual R&D Groups: An Empirical Study

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Abstract

Many organizations have responded to their dynamic, turbulent environments by organizing virtual structures and autonomous business units. Communication technologies support the emergence of such virtual organizations by enabling immediate and frequent interaction among people who are geographically distributed. A model was proposed that illustrates the relative contributions of individuals' role characteristics and network centrality on individual performance. The model hypothesizes that functional role, status, and communication role have direct influence on individual performance, and that individual centrality mediates those relationships. Using methods from research on social network analysis, a series of samples of electronic mail archives were collected for two time periods, four years apart. Other data were collected from other archives and from informants to provide performance, status, and role data. The direct contributions of functional role, status, and communication role were not supported consistently by the data; there was evidence of a direct relationship between communication role and individual performance in both time periods, and between status and individual performance only in one time period. There was fairly clear support, however, of a mediating effect of centrality in all these relationships in both time periods; functional role, status, and communication role were all significantly related to centrality, and centrality was significantly related to performance. The study illustrates how network analysis might be used to explain a significant amount of variance in individual performance in virtual groups. Future research can extend this model so that even more variance can be explained, eventually leading to better understanding of the correlates of individual performance in such groups.

Keywords: Field Study, Path Analysis, Social Science, Hierarchy of Authority, IS Project Teams, Electronic Mail, Social Network Analysis, Centrality, Roles, Individual Performance
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1.0 Introduction

As early as 1988, it was already evident that research and development (R&D) organizations had begun a transformation toward virtual groups (Drucker, 1988), yet today little is known about the extent to which this virtualization can affect the performance of group members. This study focuses on one virtual group in which members of various corporate and academic research units come together for the purpose of innovation in a large-scale research project.

Virtual groups share certain properties with face-to-face groups. Its members are engaged in a lasting relationship, pursue a common interest or goal, and influence each other through social interaction, formal and/or informal structures, and a sense of group membership. Indeed the literature on groups has focused on interaction and mutual influence (Forsythe, 1983); permanence, structure, and a sense of belonging (Baron et. al., 1982); and group identity (Aldefer et. al., 1982).

Virtual groups are distinguished, however, in many respects. Because virtual groups are geographically distributed, individuals need to overcome “space, time, and organizational boundaries (by employing) webs of communication technologies” (Lipnack and Stamps, 1997, p. 7). One conceptualization of a virtual group is a collection of individual members who never come in contact face-to-face, communicate through technology only, and each member is in a separate location. This is just one type of virtual group and a more common occurrence is a group with a few or several co-located members (Crampton, in press).” Typical virtual group members usually belong to separate organizations or organizational units and assume well-defined roles and status relationships that may be completely independent of roles and status relationships in the organizational unit employing them (Ahuja and Carley, 1999). Thus, individuals in virtual groups enjoy greater autonomy than those in traditional groups.

Our goal is to determine the factors that contribute to performance in virtual groups at the individual level. It has long been recognized that the resources that individuals bring to groups based on their roles, skills, and behaviors are important variables related to member satisfaction (Hackman, 1990; McGrath, 1984; McGrath & Altman, 1966; Steiner, 1972; Stumpf, et al., 1979). Indeed, as Steiner (1972) has suggested
"...group productivity depends upon the appropriateness of the role system that is imposed upon the members of the group, and upon the adequacy with which members perform their assigned roles" (p. 63).

Drucker has noted that especially innovative research and development often takes place in virtual, as opposed to traditional, groups. Other researchers have found that R&D groups are becoming dispersed and draw on expertise and knowledge of diverse individuals located in diverse places (Alavi, 1993; Finholt et. al., 1990). In virtual groups, the increasing specialization in R&D groups by diverse and autonomous individuals implies that analysis of the performance of the individuals is essential for more fully understanding the determinants of the performance of the R&D group itself.

Therefore, our basic goal is to understand individual performance in virtual groups, which can be influenced by a variety of factors. Specifically, we focused on the relative contributions of individuals’ role characteristics and network centrality in determining individual performance in an existing virtual group. Overall, the performance of individuals in a (virtual) group setting depends on their structural location within that group setting (i.e., centrality), which in turn depends on characteristics of their roles in that setting.

One communication technology utilized by virtual groups is electronic mail (e-mail) due to its high speed, low cost, and ability to include attachments of highly detailed or formatted materials (such as blueprints, proposals, drawings, or program code). This field study examined performance at two periods of time in a voluntary, autonomous, interorganizational virtual R&D group engaged in designing Soar (“State Operator and Result”), a large, general-purpose artificial intelligence software system. In this report, we describe the theoretical background, proposed model, research setting (the Soar group), methodology, and findings and conclusions.

This fills a gap in the literature on virtual groups because although the overall performance of a virtual group has been studied elsewhere (Ahuja & Carley, 1999), the study of the determinants of individual performance in virtual groups is still in its infancy (Staples et. al., 1998)....

2.0 Theoretical Development

Studies have provided conflicting evidence of the effects of individual characteristics on their influence over group processes. Early research on electronically mediated groups suggested that e-mail communication
was immune to influence of individual characteristics such as status or role (Sproull & Kiesler, 1986). However, more recent research has found this not to be the case. For instance, Saunders et al. (1994) found that communication patterns among individuals in computer-mediated groups are associated with functional role; under certain circumstances, individual status might even be perpetuated by electronic communication, perhaps because individuals high in status may have a disproportionately strong influence on group decisions and judgments. These individuals having greater influence exhibit higher centrality because of their communication patterns.

When examining individual characteristics in a virtual group that spans organizations, we are faced with the challenge of distinguishing between individuals’ status and roles within their “home” organization versus that in the virtual group. High formal and informal status in the “home” organization may or may not translate into high status in a virtual group. In this situation, individual characteristics such as status will have an impact on performance to the extent that the member is able to translate that status into network centrality through participation in the virtual group.

3.0 A model of individual performance in virtual groups

We suggest that in virtual groups, as individual role characteristics (functional role, status, and communication role) influence structural position as represented by individual communication patterns within the group (individual centrality), which in turn influence individual performance. Although studies of individual characteristics often include demographic characteristics such as education, skill level, tenure, and experience, we were interested in individual characteristics closely related to network characteristics. Formally stated, the general hypothesis addressed in our model (Figure 1) is that in virtual groups, the relationship between individual role characteristics and individual performance is fully or partially mediated by centrality of the person in the network.

In traditional group settings, research has found that individual performance in groups is a function of various individual characteristics such as role (Schmitt & Cohen, 1989), work experience (Galletta, 1985), and gender (Rosenthal & Hautaluoma, 1988). In virtual groups, where salience and expression of these individual characteristics may be muted by distance, network position of an individual may come into focus as a mediating factor in determining an individual’s performance.
Roles have been important targets of study for over 60 years, dating from the early 1930s when sociologists and anthropologists studied roles to explain social behavior (Linton, 1936; Mead, 1934). Role theory has emerged as a recognized discipline (Galletta & Heckman, 1990; Biddle & Thomas, 1966), and roles have been studied at societal, organizational, and group levels of analysis (Zigurs & Kozar, 1994). Indeed, as Galletta and Heckman (1990) asserted, “the nature of organizations (and other social structures) is such that they can be understood in terms of the interactions and functional dependencies between individuals and groups” (p.170).

Although the relationship between individual role characteristics and performance has not been tested in virtual groups, empirical evidence has implied this association in traditional (co-located) groups. For example, Schmitt & Cohen (1989) found that performance of individuals varied by functional role. Performance of an individual in a group or an organization has also been linked to individual characteristics such as gender (Kanter, 1977), tenure (Krackhardt & Kilduff, 1994; Galletta, 1985), and work experience (Galletta, 1985). Frost & Egri (1990) found that status of individuals in an organization is associated with their innovation-related performance.

![Figure 1: A Model of Individual Performance in Virtual Groups](image)

There are both direct and indirect effects of functional role, status, and communication role on performance in a virtual group. A direct effect on performance implies that individuals have a basic influence over others, due to factors such as formal status, previous interactions, or even potential interactions. The indirect effects assert that these individual characteristics also operate through an individual’s measure of centrality within the communication network, described below. Social network analysis presents a backdrop for presenting the mediating role of centrality.
3.1 Individual Centrality

Communication among group members can influence individual performance in traditional groups beyond the effects of formal role assignments or formal hierarchy.

Informal structure has been found to explain organizational behavior more thoroughly than formal structure (Krackhardt & Hanson, 1993). In a virtual group, communication among members is often the only visible artifact of the group’s existence.

A common measure of an individual’s position in a social network is that individual’s centrality. An individual’s centrality, or extent to which the individual is linked to people in the group, could be regarded as a measure of how closely he or she “belongs” to a virtual group. Central individuals exchange messages with a large number of members of a group. Interestingly, if an individual sends a large number of messages, it will not only change his or her own position in the structure, but others’ relative positions as well. Thus the entire structure is affected (Carley, 1991).

In traditional groups, an individual’s measure of centrality in a communication network has been empirically associated with influence (Burkhardt & Brass, 1990), cognition (Walker, 1985), attitudes towards new technology (Rice & Aydin, 1991), and other factors that may lead to superior performance. Of particular interest is the linkage between centrality and influence. Individuals who are central can exert more influence by virtue of being linked with a large number of people in the network. The likelihood of being connected with other powerful actors in the network is also higher for a central person. Ibarra (1993) found evidence for a relationship between centrality and involvement in innovation, which may also lead to superior performance. However, researchers have not yet tested the direct association of centrality with individual performance outcomes in virtual groups, nor have they examined the mediating effect of centrality on individual characteristics and performance.

Centrality can also be viewed as a source of informal power and access to various resources (Burt, 1982). The distinction between formal and informal sources of influence is that the latter arise from an actor’s position in the actual patterns of interaction rather than a formally defined position in the organizational hierarchy (Monge & Eisenberg, 1987).
Another performance-related factor that has been linked with network position is cognition. Walker (1985) found that network position, rather than function or product type, was a primary factor in explaining differences in cognition. Multiple cognitive explanations are available for the postulated relationship between centrality and performance. One explanation can be found in social information theory: Proximity to those who control relevant resources and information (Salancik & Pfeffer, 1978) provides access to situational opportunities. Another is that an individual’s structural context influences or even determines, one’s interpretations of events, perceptions, cognitions, and behaviors (Rice & Aydin, 1991; Walker, 1985). Individuals in structurally central positions can benefit from others’ experiences and perceptions. Finally, communication theory tells us that network links help construct and communicate social norms and expectations (Rogers & Kincaid, 1981). Being central enables a person to be aware of these norms and expectations and to some extent, perhaps, to even mold them according to one’s abilities and interests.

3.11 Centrality as a Mediator

Individual characteristics can be important, direct determinants of performance when their communication is influential and when role and status markers are salient. In contrast to early research on computer-mediated communication, which suggested that individual characteristics are less influential in electronically-mediated communication (Sproull & Kiesler, 1986), more recent research has found that when electronic communication is not anonymous, role and status markers can be fairly salient (Zack & McKinney, 1995). Our model reflects this in the direct link (arrow $c$) between individual role characteristics and performance.

However, there is also an indirect link between these factors through centrality (links $a$ and $b$). While there are certainly strong potential effects of centrality on performance, centrality has its own antecedents. Examples found in the literature include education and expertise (Lincoln & Miller, 1979), formal authority (Lincoln & Miller, 1979; Miller, 1986), and external work contacts or boundary spanning activities (Miller, 1986).

Ibarra (1993) showed that network centrality is determined by both personal and structural sources of power and in turn determines involvement in innovations. We suggest that in virtual groups in general, and specifically in innovation-related virtual groups, involvement in innovation may translate into improved performance for the individual in the virtual group. We extend this stream of research on determinants of individual centrality and examine the mediating effect of centrality on the relationship between individual role charac-
teristics and performance.

In summary, although certain individual characteristics have been linked with superior performance, they present a rather incomplete picture of individual performance in virtual groups. For example, individuals of high status may not always perform better than those of lower status due to the limited reach of status in some cases (confined to a particular organization or subgroup), the individuals’ lack of participation in the virtual group, or their unwillingness or inability to utilize their high status to gain centrality in the group. We propose that centrality may be a mechanism through which individual role characteristics indirectly affect performance in virtual groups, by enabling a person to become more (or less) central. Thus, it is hypothesized that the relationship between individual role characteristics and performance is mediated by centrality. Below we present a discussion of specific role characteristics and their impact on centrality and performance.

3.2 Individual role characteristics

The individual role characteristics functional role, status, and communication role, comprise the set of independent variables in our model. Such characteristics are expected to generalize to other settings, but specific operationalizations might vary slightly from group to group. General discussion of these characteristics is somewhat incomplete, so this section will also discuss briefly their operationalizations for the field study. The virtual R&D group developing Soar, described in section 4.1, is composed of faculty, senior researchers, paid staff, and graduate students. They serve information provision and information-seeking roles, and also serve developer and user roles.

Roles are important predictors of performance because they address “the degree to which individual behavior, social interactions, and the social person are constrained by social structure” (Stryker & Statham, 1983, p. 311), and emerge from the “necessary division of labor” in an organization or group (p. 332). Constraints and division of labor have great potential to affect performance dramatically, and the following discussion of functional role, status, and communication role will explore the relationship more deeply.

- Functional role

Occupational or functional roles refer to nonrelational attributes such as activities that require specific skills. Researchers studying both traditional (Barley, 1990) and computer-mediated (Saunders et al., 1994)
settings have found that communication patterns among individuals in computer-mediated groups are associated with functional role.

In the Soar group, individuals play the roles of users or developers, who are expected to have different information processing needs, and therefore different interaction patterns. In this research setting, we would expect to see differences in their level of participation in group discussions (represented by the number of messages per person), their sending and seeking behavior, and the types of people with whom they communicate. For instance, users will send bug reports and inquiries when problems arise, and have a need to receive information about new versions of software and instructions relating to maintenance. Individuals acting as developers can be expected to play the role of “teachers” and therefore send to the group information regarding research problems on which they are working, code they develop to solve these problems, and fixes in response to bug reports. Developers, in their didactic mode, are also expected to be involved in Soar workshops where work-in-progress is discussed.

The functional role of the message sender affects individual centrality. Developers are expected to be more central in the network because users will probably need to ask questions of only a few developers while developers may have to communicate changes to a large subset of the user community. Because the types of roles and their effects on centrality will vary across contexts (for example, in different industries, tasks, or types of virtual organization), specific directions of these effects are not predicted in this exploratory study.

We also posit a possible direct effect of functional role on performance, although the strength of this effect might depend on the particular organizational or environmental context. In the literature on traditional organizations, role has been linked directly with performance (Rossman, 1997; Schmitt & Cohen, 1989) and attitudes toward new technology (Rice & Aydin, 1991), and has been found to interact with other characteristics such as gender (Schmitt & Cohen, 1989).

Rossman (1997) found that the occupational role of health care aides was related to poor performance due to their need to negotiate two social organizations. Rossman’s explanation was that the aides’ official job duties are regulated by administrators who have little knowledge of the actual work environments in which the duties are to be carried out.
Attitudes toward new technology have also been connected to occupational roles. Rice and Aydin (1991) found that administrators had the most positive attitudes toward the system, were on average higher in the organization, and had a higher level of usage. On the other hand, physicians had the most negative attitude, were somewhat lower in the organization, and had the lowest level of usage. In R&D organizations, attitudes about new technologies are especially important.

In a study of 411 middle managers in 3 civil service occupational groups, Schmitt and Cohen (1989) found direct effects of occupational role on several performance variables, and interaction effects between role and demographic variables. The effects of occupational role far exceeded the effects of demographic variables, however, gender and position interacted due to uneven distribution of women in budgeting and financial roles versus outside presentation or speaking roles.

In this study, most developers are engaged in development of Soar on a full-time basis. Users, on the other hand, use Soar as one of the tools for their research and may not regard Soar as their primary research area. Therefore, developers are expected to exhibit higher Soar–related performance than users.

Based on the above discussion, the following hypotheses are presented:

**Hypothesis 1**: In a virtual group, functional role influences individual performance.

**Hypothesis 2**: In a virtual group, individual centrality mediates the influence of functional role on individual performance.

- **Status**

Research on computer-mediated communication suggests that individual characteristics such as role and status are less influential than in person-to-person situations (Sproull & Kiesler 1986). However, the need for information processing varies based on individuals' role and status in the virtual organization, resulting in different e-mail communication patterns.

Prior research has suggested that the status characteristics of group members influence their information exchange behavior. Compared to individuals of lower status, higher status professionals are more influential, communicate more frequently, use more sentences (Saunders, et al. 1994), have higher innovation-related performance (Fombrun, 1978; Frost & Egrí, 1990), and interact more, even when considering other factors such as education, seniority, and gender (Cohen and Zhou, 1991). Indeed, individual characteristics
and therefore may affect individual performance.

In this study, status refers to whether an individual is participating in the Soar project in the capacity of
a faculty member, senior researcher (including researchers at several corporations and postdoctoral fellows at
various universities), or student (in order of status, from highest to lowest)\textsuperscript{iii}. According to an author-informant,
senior researchers were, in most cases, post-doctoral fellows in research units of corporations who are con-
tinuing their research. Paid staff members were excluded from our analysis, for reasons indicated in a later
section.

There are certainly other connotations of the word “status” that are also important but very difficult to
measure. One connotation that is not considered here is reputational status, where individuals seek to maxi-
mize their influence and power within their status group, and even attempt to carry that influence and power
with them as they move into other status groups. Instead, the more objective status groups of faculty, re-
searcher, student, and staff will be used in this study.

In general, status differences among group members affect group process, structure, and perform-
ance. High status individuals are likely to be valued by the group and are treated more tolerantly (Cohen &
Zhou, 1991; Saunders et al., 1994). Their status might even be perpetuated by electronic communication
(Saunders et. al., 1994), perhaps because individuals high in status may have a disproportionately strong im-
pact on group decisions and judgments. Conversely, those low in status can sometimes be ignored even if
their input is intelligent and creative (Torrance, 1954). Higher impact and performance of high status members
of the group can also be explained by their access to more resources, higher immunity to social norms and
peer pressure (Harvey & Consalvi, 1960), and ability to work at an abstract, but not concrete, level (Adelson,
1984).\textsuperscript{iv}

Status may also have an effect on individual centrality (Morrison, 1993; Rice, 1987). Individuals with
higher formal status in general should be more central. French and Raven (1959) have suggested that status
confers legitimacy and translates into access to social capital. Also, because higher status individuals gener-
ally have control of relevant resources, more people need to communicate with them regarding their work.
Researchers have used tenure and rank as surrogates for status (Salancik & Pfeffer, 1977). We may expect that Soar faculty members will perform better than senior researchers and students. From the political perspective, high-ranking individuals may have decision-making authority enabling them to make decisions conducive to their work performance (Salancik & Pfeffer, 1977). Based on the above arguments, the following hypotheses are proposed:

**Hypothesis 3**: In a virtual group, status influences individual performance.

**Hypothesis 4**: In a virtual group, individual centrality mediates the influence of status on individual performance.

- **Communication role**

  While in traditional organizations where communication roles may be dictated by formal structure, in a virtual group members can define their own information providing or seeking roles by the manner in which they use e-mail. Arguing for study of communication roles in a social network, Rice has suggested that information flows are important aspects of structure produced by the use of computer-mediated communication. In virtual groups, it is important that individuals take on “information responsibility,” i.e., individual members be constantly aware of who in the group depend on them, and on whom they depend for important information (Drucker, 1988).

  In this study, we augment the two commonly-examined individual role characteristics described above (functional roles and status) with communication role. The two roles determine important characteristics of individuals’ relationship to a group, and can enhance learning. Communication roles can be distinguished from functional roles because the former is defined by (volitional) behavior rather than by task function. Also, group members have greater control of their communication role over a relatively short time-span. For example, a group member can switch from an information-providing role to a seeking role within a short period of time, but their formal functional roles tend to last years.

  In studies of newcomer behavior in co-located groups, information seeking has been found to be positively related to performance (Morrison, 1993). In the beginning, as new members try to become socialized in the group, they may seek more information than they provide (Lave & Wenger, 1990). However, in examining a group containing both newcomers as well as experienced members, higher performers are more likely to be those who provide information because individuals with superior knowledge of group tasks will be a source of
valuable information. Therefore, we suggest that in a virtual group, information-providing behavior, rather than information-seeking behavior, will be associated with higher individual performance.

In a virtual R&D group, information providing may substitute for ways of establishing credibility with group members that are usually available in co-located settings. It may allow people to develop contacts with those who are working in similar areas and may place them in central positions in the network. Individuals providing information might also become central in the group because those needing information seek them out for collaboration. By becoming central, these individuals are likely to perform better in the group.

Hypothesis 5: In a virtual group, communication role influences individual performance.
Hypothesis 6: In a virtual group, individual centrality mediates the influence of communication role on individual performance.

4.0 Data and Method

4.1 The Research Context: Soar

The Soar project initiated in 1982 at Carnegie Mellon University, is building a computer model and language to simulate learning and general intelligence (Carley & Wendt, 1991) to provide general problem solving capabilities (Laird et al., 1987) and even allow us to “rethink more generally the current status of cognitive science and where it should be going.” (Newell, 1990; p. x.).

The Soar virtual group is composed of corporate and academic researchers who are Soar users and developers. The Soar group communicates extensively by e-mail, their primary communication mechanism, and considers the group as an important source for ideas, findings, and stimulation. Members have a common goal of advancing Soar as an architecture through research and development. Despite this commonality of goal, members are able to work independently on their individual tasks involving widely disparate areas of expertise, such as cognition, natural language understanding, and robotics, while being available to provide their expertise to others whenever called upon.

An e-mail archive provided a unique opportunity to examine a large proportion of the group’s significant communications; because any communications of substance were archived along with the mail. Therefore, information from important phone conversations, weekly face-to-face meetings, and semi-annual workshops were included in the scope of our sample. According to an informant, the only discussions (among three principal investigators) kept off the list were related to budgeting, handled in confidence.

Over time, the Soar group has become distributed extensively throughout the United States as well as
Europe and Asia. In 1989, 18 research locations were represented, and by 1993, work had spread to 27 locations. Although Carnegie Mellon provided a disproportionate cluster, other key participants are developers and researchers at Michigan and Stanford Universities. Seven corporations involved in the Soar project represent the chemical, manufacturing, aviation, and health sectors.

The performance of the group and its members can be evaluated in terms of the main R&D task. All Soar-related publications are reported to the archives. Also, because most of the Soar members are academic or corporate researchers, they are rewarded for publishing the results of their work. Therefore, one measure of the effectiveness of research and development can be provided by the number and quality of Soar-related publications of its members. A more detailed account of the Soar virtual group can be found in Ahuja and Carley (1999).

4.2: Communication Networks Analysis

Communication network analysis is “a method of research for identifying the communication structure in a system, in which relational data about communication flows are analyzed by some type of interpersonal relationships as the unit of analysis” (Rogers & Kincaid, 1981, p. 24). A communication network consists of interconnected nodes (individuals) linked by arcs or edges (communication flows), representing informal communication patterns that crystallize over time.

Data were collected through e-mail archives, member data archives, and informants. An e-mail archive provided a unique opportunity to examine a large proportion of the group’s significant communications; because any communications of substance were archived along with the mail. Therefore, information from important phone conversations, weekly face-to-face meetings, and semi-annual workshops were included in the scope of our sample. According to an informant, the only discussions (among three principal investigators) kept off the list were related to budgeting and spending, handled in confidence. The e-mail archive included all messages exchanged among Soar members during the summers of 1989 and 1993. Two distant periods of time were used to minimize limitations of examining performance and its determinants at a single point in time (Ibarra, 1993), and to raise confidence that any findings are not attributable to one particular developmental stage or environment. The senior members approved the use of these e-mail archives for our research. Messages sent to the “official” Soar distribution lists were not included in our analysis because these lists were
created specifically to disseminate information of general use and do not affect centrality measures. Also we were interested in individual, not group performance.

Although the measure of centrality provided by social network analysis only focuses on the pattern of messaging and does not take into account the reason for messaging, the culture of the Soar group supported only messages that were useful, meaningful, and oriented toward the shared task. According to an informant, messages that failed to meet those criteria were ignored by the group and therefore would be unlikely to result in higher centrality even in a relatively short period of time.

Of potential concern would be the extent to which messages sent to specialized lists were dropped. Analysis showed that most of the messages sent to those lists were also forwarded to the general S-Group archive, which are dropped for every member equally. Those that were not sent to the general archive reflected matters of an administrative nature and address items outside the scope of the Soar task. Examples include requests from Soar members to distribute documents, requests for information from non-members, and notices of software upgrades.

The second source of information, the Soar group member data archives, allowed us to collect information on functional role, status, and even on the publications by each of the group members. Not all the functional role information was available from the member databases, however. We used key members of the group as informants on member functional roles. These informants also provided background and historical information on the Soar group.

4.3 Measurement

- **Functional role and status:**

  Although status (faculty, student, senior researcher) information was usually straightforward to assess, role and status information not available in the Soar membership archives was obtained by interviewing three key individuals from each time period being studied. These individuals were identified by one of the authors, an active member of the Soar group. They were mostly faculty members at the three main universities involved in the Soar group and tended to be developers rather than users. When there was doubt in the informants’ minds regarding a certain individual’s role as a user, developer or “other,” e-mail messages sent by them were studied carefully to determine their role in the group. Developers are individuals who developed the “Lisp” or
“C” code for the Soar architecture. Users are individuals who use the Soar architecture to build artificial intelligence models or applications. Ambiguous roles for three individuals in 1989 and two individuals in 1993 had to be resolved in this manner.

- **Communication role:**
  Communication role is operationalized as information-providing versus information-seeking behavior. Members send a variety of information types (announcements, questions or responses) in their e-mail messages. We content-analyzed each message to determine to which of the three categories the message belonged. Information-providing behavior is represented by the number of announcements and responses (to questions) sent by an individual. Questions asked by an individual represent his or her information-seeking behavior. Communication role is indicated by the ratio of the sum of announcements and responses to questions sent to the group by the individual. A high ratio reveals that the individual sent more information providing messages than information-seeking messages. A low ratio indicates a pattern of seeking information. In contrast to functional role, communication role is measured as a continuous variable rather than a discrete variable.

  Such a metric is imperfect, in that individuals could achieve the same ratio in countless ways. For example, two individuals could achieve the same 1:1 ratio with one message sent and one received, or 10 messages sent and 10 received. Methods of attempting to correct this problem range from weighing some individuals more heavily than others, to removing data points below an arbitrary level. We chose to retain all nodes (above a minimum, “temporary visitor” threshold) and preserve a ratio scale in this study, with the caution that this single measure does not tell the entire story; taken together with centrality and status measures, a more complete picture can be viewed.\textsuperscript{vi}

  Messages were read and coded by one of the authors and one other coder. Every two weeks, for a total of fifteen times, we randomly selected thirty messages each week from each coder’s database and matched them. The inter-coder reliability was consistently higher than 90 percent.

- **Centrality:**
Freeman (1979) proposed three separate measures of centrality, including degree centrality (involvement), distance centrality (power), and betweenness (information control). We are interested in a person’s involvement in the group and therefore utilize the measure of degree centrality.

Degree centrality is based on the number of nodes (individuals) to which a node is adjacent (Scott, 1991), or connected by an arc. A node is central if it has a higher degree than others in the network. The major limitation of this measure of centrality is that it should only be used to compare centrality scores within a single network. However, this limitation can be overcome by using scores standardized for network size. We did, in fact, use standardized scores in our analysis.

An individual with low degree is seen as isolated from direct involvement with most of the others in the network and is cut off from active participation in the ongoing communication process. A central person, on the other hand, is heavily involved in the network (Freeman, 1979). In Figure 2, node C is most central because it is adjacent to three other nodes. Node D is peripheral because it is adjacent to only one other node.

Degree centrality is posited to relate to publication performance for two reasons. First, it is likely that the number of links for a particular individual would increase as the value and/or amount of information possessed by that individual increases. This larger base of knowledge would be natural fodder for publications. Also, each link represents an additional potential collaborator and/or coauthor. A large number of Soar publications are jointly authored, raising the probability that such collaborations would correspond to a large number of communications.

To compute centrality, who-to-whom information was recorded for each of the selected messages in the form of social network matrices. A social network matrix is a binary matrix that places senders on each row and recipients on each column. If a link (one or more messages) between the two individuals is present, a 1 is placed into that cell. The absence of a link is represented by a 0.
The social network software package UCINET IV (Borgatti, Everett, & Freeman, 1992) was used to convert these matrices into individual centrality scores. In UCINET, one can choose to treat data as symmetric or asymmetric while computing degree centrality. In order to preserve status asymmetry, we chose to treat our data as asymmetric, following Ibarra and Andrews (1993). This means that in computing centrality, sending and receiving are treated as distinct activities.

- **Performance**

  Individual performance is defined here as the output of an individual’s efforts with regard to Soar. Because Soar is an inter-organizational group (individuals are members of one organization while also members of the Soar group that runs across organizations), it was important to distinguish between individuals’ overall performance from their Soar-related performance.

  In a study of individual performance in a group setting, it is important to establish the consistency of group and individual goals. In this group, three goals were shared by both the overall group and its members: (1) advancement of artificial intelligence research; (2) making progress on the system itself (the Soar architecture) by completing the project effectively and improving the user interface; and (3) publication of incremental progress on the project. The latter goal was shared by the group overall because it served to bring visibility to the group. The three goals were highly correlated, as visibility brought increased opportunity for funding, additional funding brought more resources to bear on the project, and additional resources made it possible to make progress more quickly, yielding more publications and visibility.

  We obtained the publication information from the publication directory. Members of Soar are asked to report all their Soar-related publications to this directory. We considered several alternative measures of individual contribution to the common group goal of improving the Soar architecture. For example, we considered using the number of lines of code. However, there is a great deal of variance in the type of code (languages, tools, etc.) generated by developers and users. Because of tool and specific task differences, a large number of lines of code does not necessarily imply greater contribution. It was considered more feasible to examine the publications, evaluating the quality as well as their quantity of the target journals.
Most of those members not employed by academic institutions are employed by research organizations or research units of corporations that also evaluate performance based on publications. Therefore, individual performance is measured in terms of the quantity (weighted by quality\textsuperscript{viii}) of Soar-related publications produced during the period of study and two years after the study period (to allow for writing and revision time of research reports). The group norm in Soar is to include only those individuals as co-authors who took an active part in the research or writing, so co-authored papers received the same credit as single authored papers for each of the authors. To be consistent with our goal of measuring only Soar-related performance, individual publications were only counted if they were related to the Soar virtual group.

The Soar group employs members of paid staff who are responsible for managing the day-to-day operations and resources. We did not include these individuals in our analysis because our goal was to study performance of the main tasks of research and development. Paid staff members are not evaluated or rewarded based on their research and development productivity.

4.4 Research Sample

All E-mail messages from the summers (June, July and August) of 1989 and 1993 were included in this study. Summer months were considered appropriate because in the academic world, most of the research is performed during this period of low teaching responsibility.

Although we wanted to include e-mail messages from all Soar members, we also wanted to refrain from including the casual inquirers in this study. Therefore, we decided to include messages from all individuals who sent more than one message to the group and received more than two responses from the group. These selection criteria were chosen because a typical casual exchange consists of one message of inquiry and two responses from one of the Soar administrators. One response contains an acknowledgment and the other consists of a description of the Soar architecture and participants. By using the above selection criteria, we were able to ensure that only the members with more than a casual contact with the Soar group were included in the study.

The size of the group in each sample is shown in Table 1.
The time lag of four years between the two study periods was chosen for a number of reasons. First, the composition of the group and therefore the structural position of group members can be expected to change considerably as a result of the death in 1991 of the founder of the Soar group, Allen Newell. Second, many active members of the group are students who graduate from undergraduate, graduate to post-doctoral fellows and then sometimes become senior researchers. In principle, the structure of the group might change as the students change their status or graduate. In four years, after 1989, most of the students had changed their status. Also, the number of people who know about the group and use Soar has been continually expanding. Finally, improved methods of communication reduced the number of messages devoted to coordination of events and tasks (and appear to have reduced the overall number of messages dramatically). In the later period, Frequently-Asked Questions lists were made available on line, documentation was improved, and routines for allocating resources were adopted.

Tables 2 and 3 show the composition of the Soar group during the two study periods. As can be seen from table 2, the number of both users and developers increased between periods. Table 3 shows that while the number of students decreased, the number of senior researchers (including corporate researchers and post-doctoral fellows) more than doubled between the periods.

### Table 1 - Sample size for each period

<table>
<thead>
<tr>
<th></th>
<th>People</th>
<th>Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>53</td>
<td>1,126</td>
</tr>
<tr>
<td>1993</td>
<td>65</td>
<td>655</td>
</tr>
</tbody>
</table>

(Note: 23 members are common to both time periods)

### Table 2 – Group composition for each period by role

<table>
<thead>
<tr>
<th></th>
<th>Users</th>
<th>Developers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>39</td>
<td>14</td>
</tr>
<tr>
<td>1993</td>
<td>45</td>
<td>20</td>
</tr>
</tbody>
</table>

### Table 3 – Group composition for each period by status

<table>
<thead>
<tr>
<th></th>
<th>Faculty</th>
<th>Senior Researchers</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>12</td>
<td>10</td>
<td>31</td>
</tr>
<tr>
<td>1993</td>
<td>11</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>
The characteristics of communication found in the Soar group was found to be as follows. The communication was mostly about technical matters (how do I do X, what do people know about this bug, etc.). Very few messages were regarding social matters. Frequently, inquiries were made by less knowledgeable individuals and answered by more knowledgeable members. Announcements typically provided information regarding new releases, bug fix announcements, new papers, code examples, meetings and workshops announcements, etc.

We did not observe occurrences of messages related to personal interaction and productivity. For example, we did not see any request for editing papers or babysitting. Most messages were task-focused and related to developing or using the Soar architecture. Overall, our observations indicate that in this R&D virtual group, the goal is to produce knowledge, and those who have more knowledge and greater expertise tend to be high performers. The kinds of information that demonstrates expertise about Soar that allow members to publish more are provided below. These also serve as examples of announcements, questions, and responses.

Announcement

“The NL code that I am using for the NTD+NL integration is now available in the directory /afs/cs.cmu.edu/project/soar/utc/nl/integ.nl

In addition, the file usage-notes contains a rudimentary and probably incomplete description of the elements required from a Soar model that wishes to interface directly with this version of NL. – Ian”

Questions:

“Am I wrong in assuming that the "Release Notes" are made redundant by the Soar 6 manual? I used to include a copy of the notes with the old manual, but it seems that all the material therein is now covered in the manual. Please let me know if you disagree! – Marla”

Or

“Does anyone have Soar 6 code to do lookahead for two player games? This used to be in the default code, but it was removed some time ago. - Terry

Responses to inquiries:

Ralph, Enclosed is the README file we send out to people seeking Soar. If your friends have any other questions, they can send mail to <email address>. They should also send their physical mail addresses to <soar-doc@cs.cmu.edu> and ask for the manual & release notes.
5.0 Results
This paper examines the linkages among individual role characteristics, centrality, and individual performance. It suggests a direct link between individual role characteristics and performance, and also suggests a mediating role of centrality in the relationship between performance and individual role characteristics.

Venkataraman (1989) has recommended using structural modeling to test mediating fit between variables. We tested the hypotheses using partial least squares (PLS) analysis, a second generation multivariate regression-based technique for the assessment and estimation of structural models (Fornell & Bookstein, 1982; Wold, 1982; Löhmoller, 1984). PLS has been used as an alternative to LISREL analysis, which uses the covariance fitting approach for estimating structural equations, and employs a maximum likelihood estimation (MLE) procedure that places more rigid constraints on the data. PLS avoids many of these limitations by following a components-based strategy (Fornell & Bookstein, 1982; Tabachnik & Fidell, 1989). While PLS accomplishes predictive accuracy (Anderson & Gerbing, 1988), its parameter estimates are less than optimal for bias and consistency due to its information limitations. A second PLS limitation is that it makes no prior distributional assumptions about the data and therefore provides no significance tests and estimates of confidence intervals for the path coefficients.

To estimate the significance of the path coefficients, we used a bootstrapping approach, where 100 random samples of observations (with replacement) were generated from the original dataset. The path coefficients were re-estimated using each one of these samples. The resultant vector of parameter estimates was used to compute the parameter means and standard errors needed for computing the significance of the path coefficients. We replicated this approach with two additional iterations of 250 and 500 random samples of observations with replacement to assess the stability of the significance of the path coefficients. This overall approach has been recommended by Bollen and Stine (1992) and has become a standard practice in estimating the significance of path coefficients in PLS models (e.g., Howell & Higgins, 1990; Compeau & Higgins, 1995).

Figures 3 and 4 show the path coefficients based on 1989 and 1993 data respectively. Hypotheses 1 through 3 test the direct effects of individual role characteristics (functional role in Hypotheses 1, status in Hypothesis 3, communication role in Hypothesis 5) on performance.
Functional role did not have a direct effect on performance in 1989 or in 1993. Hypothesis 1 is not supported. Status did not have a direct effect on performance in 1989 but did in 1993, providing partial support for Hypothesis 3—higher-ranking individuals tended to have higher performance in 1993 than lower-ranking individuals. Communication role had significant direct effects on performance in both 1989 and 1993. Hypothesis 5 is supported—information providers tended to have higher performance than information seekers.

Figure 3: Individual role characteristics, centrality, and performance (1989)

Figure 4: Individual role characteristics, centrality, and performance (1993)

* p<.1; ** p<.05; *** p<.01

Hypotheses 2, 4, and 6 examined the mediating effect of centrality on the relationship of functional role, status, and communication role with performance. As Hypothesis 2 predicted, role had a significant effect on centrality in 1989 as well as in 1993; developers seemed to exhibit greater performance than users. The path between centrality and performance was also found to be significant and positive in both years. The sig-
significant paths from functional role to centrality and centrality to performance imply that centrality mediates the relationship between role and performance. Therefore, Hypothesis 2 is supported.

The paths between status and centrality and centrality and performance were also significant in both years (both positive). Thus, hypothesis 4 is also supported. The effect of communication role on performance follows a similar pattern, with developers being more central and central individuals having higher performance. Therefore, communication role’s effect on performance is mediated by centrality of the individual, providing support for Hypothesis 6.

Given that communication role had significant direct as well as indirect effects on performance in both years, we conclude that a partial mediating effect of centrality on this relationship exists.

6.0 Discussion

Evidence from both study periods provides support for the assertion that an individual’s performance in a distributed group is an outcome of the individual characteristics of functional role, status, and communication role, mediated by the individual’s centrality in the group. Overall, centrality was a stronger direct predictor of performance than individual characteristics.

Functional role seemed to enable a person to achieve centrality in the group. Functional role did not affect performance directly, but indirectly by influencing a person’s centrality. Evidence from the 1993 sample suggests that the higher the status of the individual, the better performance is likely to be; in this study, faculty in the second study period performed better than students and senior researchers. However, a more consistent finding is that higher status may help an individual to become central in the group thereby enabling them to perform better. It appears that the extent to which centrality mediates the effect of a particular individual characteristic on performance depends on the individual characteristic being studied and the level of maturity of the group.

Data from both 1989 and 1993 showed a strong relationship between the third examined role characteristic of individuals - communication role - and performance (Figures 3 and 4). The findings suggest that communication role is a more consistent predictor of performance in virtual R&D groups than functional role and status. Thus, the manner in which an individual interacts with the virtual members of the group appears to be an important factor in determining the individual’s performance in the group. Centrality also (partially) medi-
ated the relationship between communication role and individual performance.

The findings related to communication role are important because in contrast with functional role and status, communication role depends upon individual behavior and is a volitional determinant of performance. While members may not have any control over their functional role and status in the short-term, they are likely to have volitional control over their behavior (and therefore their communicational role). Our results underscore the importance of distinguishing between volitional and non-volitional individual characteristics in virtual groups.

We found that individuals who tend to provide more information to the group than they seek will perform better. To further test the relationship of communication role and performance, we divided Soar members into those who are seekers, balanced, and providers, and performed a one-way ANOVA with performance. The three groups were found to be significantly different in their performance both in 1989 (p < .01) and in 1993 (p < .05).

This finding contributes to the existing literature on new member socialization by examining information-seeking behavior for all members, rather than newcomers alone. Our finding is not consistent with studies on socialization that found that information seeking was positively related to performance (Morrison, 1993). Several possibilities exist. First, as discussed above, newcomer behavior might be unique and not generalizable to all group members. Second, information providing might indeed be a more potent predictor of performance than information seeking. Finally, information providing might be more important in virtual R&D groups and is rewarded through higher centrality. Certainly, these questions present potential avenues for future research.

In our study, while it is the case that the newcomers ask many questions, it is not clear whether doing so is related to performance. In the Soar group, productivity is mainly the production of papers (research reports and publications). Writing such papers is a time consuming process and requires that research be done up front. This creates a lag in which newcomers will naturally be less productive than established group members. This may reduce the relationship between information seeking and productivity. Further, these papers involve idea creation and communication of new knowledge. Individuals who make more announcements are often those innovators who come up with the ideas that in turn become papers.

Frequent publishers may ask more questions or may be sought out more and have more to say to
others. An examination of the e-mails reveals that most of the discussion precedes publication. Someone will come up with a question or idea, and then check it out via e-mail or request advice or an answer. After the discussion, a paper is often presented at a Soar workshop, and then eventually the paper turns into a publication.

Questions are often of the form “who knows how to do this?” or “what did you find out about this?” People who are likely to answer such questions are the people who have the knowledge that needs to be communicated beyond the group as well in the form of papers. Sometimes questions led a responder to say, “I don't know, but I will figure it out” which in turn then led to the production of an academic paper. Information providing may be an indication of superior knowledge, expertise, and active involvement in the creation and pursuit of knowledge.

Since the work of this group is knowledge-based, if information providing is related to expertise it should be related to performance. Further, these results suggest that there may be a tendency for communicative activity in one medium (e-mail) to carry over into communicative activity in another (paper production). This would be an important point for additional research.

Of course, it is unlikely to increase performance merely by sending more messages over the short term. The culture of the group was that members tended to send only meaningful communications; members were politely asked to refrain from sending messages that did not contribute to the project. In general, therefore, the correlations represent more than individual, but collective acts that fit into the present culture.

In the Soar group, members who provided information were often senior members with heavy investment in the group and extensive expertise. Thus, apart from transferring knowledge, information providing may be a mechanism that the core members of the Soar group utilize to facilitate the process of socializing new members in the group.

Information seeking and providing form a process of socialization, continued learning and organizational memory in virtual groups. One goal of a collaborative effort such as the one observed in the Soar group is to teach the newcomers so that the long-term stability of the group can be assured. In virtual groups, stability and cohesiveness of the group need continual attention because members may not meet each other as
regularly as they would in a co-located group. Once trained, the very individuals who seek information can adopt an information-providing position.

Unfortunately, the literature on socialization in traditional groups has found that information seeking is also associated with intention to leave (Morrison, 1993). In a virtual group, where the goal of information providing by senior members is that newcomers will, in time, become core members of the group, this pattern can be disturbing. We did not examine exit intentions or any relationships between those intentions and behaviors, but present such tests as an avenue for future research.

In an attempt to explain the different status findings across two time periods, we examined the changes that took place in the group over time. One major change involved leadership of the group after the death of founder Allen Newell between the two time periods. This led to diffusion of leadership among a few key members of the group, which corroborates with the lower centralization score in 1993. It is possible that other factors associated with maturity of a group account for a change in structure of the group over time.

Another plausible explanation for the differences between 1989 and 1993 may be found in the way in which the group’s structure changed in 1993 (see Table 5). We examined the network structure of the group using social network techniques of centralization and hierarchical levels for various task networks (networks formed by e-mail exchange among people working on specific tasks). Details on the structure of these task networks in the Soar group and their measurements can be found elsewhere (Ahuja & Carley, 1999). In 1993, the group showed an indication of having structured itself in a more hierarchical manner (indicated by somewhat higher scores on hierarchical levels measure) but with less centralization than in 1989. The results show that in this environment (created by more hierarchy but less centralization), status of an individual has a direct influence on performance, as is the case in traditional groups. This may imply that as virtual groups mature, they start behaving in a manner that is more consistent with traditional groups.

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<tbody>
<tr>
<td>Design</td>
<td>0.90</td>
<td>0.81</td>
<td>0.55</td>
<td>0.80</td>
</tr>
<tr>
<td>Resource Management</td>
<td>0.83</td>
<td>0.82</td>
<td>0.55</td>
<td>0.66</td>
</tr>
<tr>
<td>Group Maintenance</td>
<td>0.90</td>
<td>0.84</td>
<td>0.80</td>
<td>0.70</td>
</tr>
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</table>

In summary, the findings provide support for the assertion that an individual’s performance in a virtual
group is an outcome of the individual role characteristics mediated by the individual’s centrality in the group.

7.0 Contributions

This study examines the relationships among individual role characteristics, centrality, and individual performance in a virtual group. The results provide evidence across two time periods that the centrality of an individual in a virtual group is determined by his or her functional role, status and the manner in which he or she interacts with the group. These effects on specific functional roles and status will obviously vary with context as different functional roles and status types apply to the situation. However, in general the findings indicate that centrality can be, at least in part, predicted by functional role and status and that it is centrality, rather than individual role characteristics that consistently and directly predicts performance. Thus, even low status individuals, if they can gain centrality, can achieve high performance. It appears that the extent to which centrality mediates the individual role characteristics depends on the particular context of the virtual group. Future studies should explore this relationship further to better understand this mechanism of mediation.

This study extends the research in the areas of virtual groups to the R&D and software development environments. It provides a basis for theory building for this increasingly popular type of work environment. By building on this study, researchers can begin to address some of the issues related to virtual design groups, and increase their efficiency and performance. Researchers can also potentially build on this research to design specifications for computer support for virtual groups.

Single group studies, like this one, are limited in the extent to which their findings may be generalized to other contexts. Although the findings might only apply to the Soar group, they provide some insights on the relationships between individual role characteristics and individual performance at two periods of time in a group’s evolution. Similar studies in other settings can test if the findings can be applied to virtual organizations in general. Beyond the particular group examined, the sample has very heavy representation from university-related individuals, and its results should not automatically be extrapolated to other samples such as those in for-profit corporations. Fortunately, research and development organizations in a variety of settings share the academy’s focus on research projects, publications, and presentations. Also, the task is knowledge-based, status differentials exist, and membership is dynamic as in other virtual groups.
Another limitation of the study is the lack of differential analysis of “balanced” communicators who sent and received few messages from those who sent and received many messages. Fortunately, in our case most participants fell clearly into the roles of seekers and providers. Future research might develop a two-dimensional categorization scheme for exploring communication role identification with different R&D groups.

Field studies are also limited by the fact that they have no control over the factors that might interfere with the phenomena under investigation. For example, economic, social, and organizational factors can interfere with group and organizational processes. However, comparing two datasets from the same group representing two different periods has been likened to a quasi-experiment in a natural setting (Lee, 1987). A related limitation is that the lack of experience of organizations with e-mail during the period studied probably increases the variation of organizations’ responses as they employ such communication tools for the first time. However, this difficulty is minimized in this study because the organizations represented already had been using e-mail quite heavily for over a decade before the sampling periods, and their culture therefore included e-mail as a routine communication mechanism.

This study also focused only on e-mail, excluding other modes of communication such as personal meetings, phone calls, and letters. Fortunately, e-mail was the primary mechanism for group-related communications in this sample, because of the geographic dispersion of the group, the low cost of e-mail, and its ability to include code segments or other attachments.

Finally, the measure of centrality ignored volume and focused only on whether or not communication existed between two individuals. Similarly, the performance measurement included only one type of productivity. In a research and development group, other performance measures assessing the quantity and quality of software generated can also be important. However, such measures usually include significant challenges to inter-rater reliability, stability, and objectivity.

In spite of these limitations, this study offers many significant implications for R&D groups. The cooperative culture in Soar fostered sharing of ideas, valuing co-authored papers as highly as individually-authored papers, and giving due recognition to ideas of others even when the ideas had not been published. This culture was likely instrumental in encouraging development of information providers. Our finding that people who
are information providers perform better individually implies that R&D group members have a self-interest in sharing knowledge. Future researchers should further explore this linkage. Our understanding of other virtual groups can be informed by our results if they are similarly cooperative and also share many of Soar’s other characteristics, such as its role and status differentiation, its focus on knowledge-intensive work, and its measurement of productivity through creation of knowledge. One might consider this as creating a culture of “networking” (Baker, 1994). One possible mechanism would be to consciously create highly central personnel by placing talented and potentially innovative individuals on multiple teams and projects so that they can increase the number of people they know and to whom they can provide information.

As organizations continue to experiment with, and adopt, new organizational forms that rely less on formal structures and more on informal mechanisms, researchers will need to understand the extent to which these informal mechanisms have direct influence on behavior and performance. Studies are needed that will investigate how these informal mechanisms, and in particular the informal social network, influence individual performance. This study was intended to provide an early step in achieving that understanding.

BIBLIOGRAPHY


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Linton, R. (1936). The Study of Man, Appleton-Century New York, NY


**END NOTES**

i One variable not included in this model is experience, usually measured as the number of years in a particular position. Our research site involved very new technology, and by definition the group’s individuals were inexperienced across the board. We found that the number of years in the group, the only experience item that was available, was highly correlated with (occupational) status. The status variable therefore served as a surrogate for experience for this pool of data, and a separate experience variable was not included in our model.

ii There did not appear to be liaison or intermediate roles in the Soar community, where a “blurring” of functional role would exist. As section 3 describes, analysis of mail messages helped resolve the role of the sender and/or receiver.

iii Although there are roles and heightened status differences among Soar members, there is no formal organizational chart.

iv Besides higher ability to work at a concrete level, lower status individuals were also found to be better able to differentiate the means to achieve long- and short-term goals (Walker, 1985).

v Although in general, it may be that the newcomers have more technical knowledge (having recently been doing university research), in R&D groups, such as this one, this is not likely to be the case. In SOAR, as in other R&D groups, technical discussions take the form of task-related communication which require knowledge specific to the group’s particular context.
The danger is that the continuum does not necessarily range from “high” to “low.” Most linear analysis would run into difficulties if a large number of intermediate (balanced) cases would exist. Fortunately, most members were easily categorized, and those who were balanced usually had a very small number of messages. Therefore the effect of this bias was minimal. In future studies, however, researchers would perhaps need to plot the results and/or perhaps identify a lower threshold level for considering what is “high” versus “low,” perhaps assigning a maximum score at a level above, for instance, sending 50% of what is received.

There are alternative ways in which the networks of connections among people could have been constructed which would affect how centrality was measured. For example, we could have used the volume of messages or the total length of messages. Such variations might affect the outcome. In this particular group, however, message length did not appear to be a consistent indicator of role-based behavior. Moreover, people who sent to more people often tended to send more often. Further, the number of people that were interacted with is actually a better indicator of overall influence on the group than the volume of messages as it uncovers the range of influence.

Quality of the publications was measured on a five-point scale (5= top ranking journal, 4= middle-tier journal, 3= refereed conference proceedings, book chapters and remaining journals, 2= non-refereed conference proceedings, and 1= technical report or a working paper).

Deleted from

“3.0: Individual Centrality”:

While formal organizational structure mediates the purpose and direction of information and influence in traditional organizations (Rice & Aydin, 1991), virtual R&D groups such as the one examined here seem to form their own informal social network structure over time (Ahuja & Carley, 1999).

“Communication role”

For example, members in certain roles might exchange needed information to increase what might be perceived as relatively low power and influence.