THE COMMUNICATION NETWORK STRUCTURES

OF R & D UNITS*

Ricardo Arechavala-Vargas
Kino University
Heriosillo, Sonora

Working Paper 86-5
November, 1986

* This research was supported by NSP (Grant No. ISI-8304340: The Relatioship of Teas Social Structure to Team Productivity; directed by Dr. Bernard P. Cohen), and by Mexico's National Council for Science and Technology.

THE COMMUNICATION NETWORK STRUCTURES OF R&D UNITS

1. Introduction:

Several studies from the sociology of science have underscored the importance of communication networks in scientific disciplines (Crane 1972; Zuckerman 1967) and within academic organizations (Friedkin 1978). A basic theme found in this literature is that the density of interaction among the members of a network is closely associated with the rate of advance in that discipline. More recent studies (Blau 1974, 1978; Brieger 1976) also show that disciplinary networks (or "invisible colleges") have a differentiated structure, with a core of more intensely communicating individuals, and a periphery, where Individuals are less intensely communicating among themselves and with the network core. According to these studies, relevant problems in the field and the validity of methods and techniques are defined by those at the core of the networks, while members at the periphery generally follow and accept those decisions.

Studies on communication in R&D organizations (Allen 1977; Tushman 1978, 1979) have focused on information exchange and have discovered useful roles played within research organizations by people who are more active than others In terms of their information exchange behavior. They have become known in the literature as "gatekeepers" for their ability to bring useful information into their organization and for the role they play in keeping the organization up to date in technical fields. Tushman also has identified specific boundary roles related to the ways in which organizations bring in information from the environment, and has related those roles to project task characteristics, interdependence and perceived environmental variability (Tushman, 1977, 1978).

Naturally, attempts have been made to develop ways in which to identify those individuals that are performing the gatekeeper function. Fischer and Rosen (1982) have used this notion to search for the "latent information star", i.e. those individuals who may assume the gatekeeper role under the right circumstances, in an attempt to derive useful applications of the "gatekeeper" concept for R&D organizations. Also, Fischer (1980) has reviewed the literature on scientific and technical communication and provided a series of guidelines for managers with respect to ways in which communication among scientists and engineers might be promoted.

In general, however, these studies have dealt almost exclusively with networks that encompass whole organizations. A step further is to study those processes through which Information is distributed and generated within the organization. For this purpose, the proper unit of analysis to use is the project team: those units set up to solve specific problems. It is at this level that R&D organizations define those tasks that enable thea to reach their aajor goals, and it is at this level that the research activity succeeds or fails. Thus, in order to understand the processes through which research teaas achieve their goals, one of the first places to look at is the specific coMunlcation structures of R&D teaas and subunits. Knowledge of the network properties of units set up to work on discrete tasks and of their organizational environaents should increase our understanding of the coaaunication processes that take place within R&D organizations. Also, to the degree that previous studies have tended to assuae that coaaunication behavior in these organizations is coapletely or priaarily defined by inforaational exchange, they have left unattended aany diaensions of interaction that have a strong influence in shaping the research activity.

Tushaan and Nadler, in their review of the field of coaaunication in R&D organizations (Tushaan and Nadler 1980) have pointed out that, in spite of the quantity of publications in the field, there is a lack of a conceptual fraaework that would unify contributions and advances aade so far. Such a conceptual fraaework should provide an understanding of the processes that aake research a very difficult and uncertain activity. In which ways aay an organization proaote the right kinds of interaction aaong researchers? What kind of coaaunication structure is optiaal under different circuastances? What kinds of interaction aay be aore closely associated with better perforaance?

This needed conceptual fraaework should be able to take advantage of tools developed by organizational theory and the sociology of science and froa the R&D aanageaent literature. In the following section we present a aodel of the process developed as part of a large-scale research project dealing with the foras of organization eaployed in industrial R&D teaas, and section three will present soae eapirical results based on that aodel.

2. The Model.

The research process in organizational settings aay be conceptualized in teras of the "bounded rationality" aodel of organizational decision aaking (March and Siaon 1958). Under this aodel, solutions to probleas are not chosen on the basis of their ability to satisfy a set of optiaal criteria, but on the basis of their ability to satisfy a set of ainiaua requirements. A version of this aodel has been adapted by Frischauth and Allen (Frischauth and Allen, 1969) for aodeling technical problea solving processes.

Organizations respond to signals or stiauli received froa their environaent by perforaing sets of actions according to programs that aay be previously defined to various degrees. At a fire station, for example, the sounding of the alarm initiates a fairly routinized program. In other instances, there is a large compnonent in the program that consists not of a well-defined series of actions, but rather a set of open-ended search activities. If some of the Information that is needed in order to perform the proper set of actions is not available, then one or several of these actions in the program may consist precisely in performing the search activities needed to gather that information. In the context of the "bounded rationality" model, the research process may be thought of as a "second order" search program, i.e. an action program that has as one of its main components one that is in itself a search program: a search for solutions that satisfy the requirements of a new problem.

Within R&D organizations, research teams are assembled to achieve specific technical goals. Individuals are usually assigned to these teams formally, either for a fraction of their professional time, or for a specific period, and the unit is usually Identified with the project it is working on. Although individual formal evaluations will not necessarily depend on performance of a specific unit as such, individuals are expected to interact in ways that enable the team to achieve its goals. Thus, the unit itself may be viewed as an organizational subunit performing action programs directed at solving technical problems in response to inputs received from the parent organization and the external environment. On this basis, using the project team as the unit of analysis ought to help considerably in understanding the processes that affect organizational performance.

In individual academic research, the process may be thought of as a search that each person performs over his own resources, based on his own perspective of the problem. In order to arrive at a solution, the Investigator searches among his own ideas, knowledge, and expertise as the resources available to him, in order to design a set of activities that will provide him with a solution to the problem as he himself defines it.

In R&D units, problems are frequently defined externally, that is to say, teams are usually assembled to solve previously defined problems. Even when this is not the case, there will be at least as many different perspectives on the problem as there are members in the unit. Under these circumstances, the search activity may proceed as a sum of individual searches, with each member searching over his own resources, and according to his own perspective of the problem. Alternatively, if at least some of the unit members may have information, either about other members' perspectives of the problem, or about the resources available to them, then research may proceed as a collective search over the resources available to different members, and according to different perspectives of the problem at the same time. Naturally, in the latter case we should expect an increase in the probability that the research unit will find a "satisfactory" solution to the problem.

Whether a unit will efficiently utilize Its resources or not, then, is dependent on Its ability to bring thea together with the perspectives of the problea that aay also be available. If it is to be aore effective than a set of individual searches, it can only do it through the presence of those Interpersonal links that enable the flow of resources froa those parts of the network where they are available, to those other parts where they are needed. Thus, it is the properties of the coaaunication networks that aake possible the synergistic effect that is sought when teaas are built to achieve goals that are beyond the possibilities of an individual researcher.

However, resources available in the unit require specific kinds of interaction in order to be usefully exchanged and used aaong teaa aeabers. It is not enough to know that inforaation aay flow froa soae parts in the unit to others; other resources require the presence of specific kinds of interaction different froa the Inforaation-exchange relationship. Between any two aeabers, for exaaple, the relationship aay be such that inforaation can be exchanged, but neither of thea would approach the other in order to ask for technical assistance. Furtheraore, a aeaber with an interesting, but not well developed Idea, aay or aay not approach other aeabers in order to enlist their help in further developing or evaluating it. Even though he would approach the saae people for technical assistance or inforaation, relationships aay be such that he would not approach thea as "sounding board" for his ideas, because of a lack of personal trust in the corresponding relationships. All of these, and still other functions, need to be perforaed, and resources exchanged, if the unit is to achieve its research goals.

Within a given research unit, aeabers aay or aay not have the proper kinds of interaction that facilitate exchanges with regard to their different perspectives of the problea, or with regard to the resources available to each of thea. To the degree that R&D units are usually asseabled with the criterion of choosing the proper coabination of specialists (froa aaong the available huaan resources), soae of the aeabers will be in a position to provide others with their own technical expertise, as different perspectives of the problea are used in atteapts to solve it. "Technical Assistance" relationships will, in principle, be a way to increase the efficiency of the search process and, therefore, they will increase the likelihood of arriving at a satisfactory solution to the problea.

In order for the search process to be effective, other resources aust flow within the unit, and other processes aust also take place besides aeabers sharing technical expertise. New ideas aust be detected, developed, and evaluated, individual search processes aust be coordinated, and relevant inforaation aust reach the proper people at the right tiae.

However, not every teaa is able to develop the right kinds of interaction aaong its aeabers and, for any given dyad in the unit, we

·ay still find either the presence or the absence of the proper kind of relationship between the persons Involved. Moreover, the relationship for any given pair of individuals Bay be such that one of then may be in a position to provide the other with technical assistance, but still the opposite say not necessarily be true. Of course, under the present argument, in those cases where both members can gain access to each other's perspective of the problem and/or resources, the likelihood of finding a satisfactory solution will be higher. Thus, we may expect that those units whose communication structures have mutual links through which the requirements of the problem, as well as the members' resources, may be addressed, will have a better performance than those units in which this is not the case.

Furthermore, at the unit level, the presence of given kinds of relationships among the members will configure a network whose properties will substantially affect the flow of resources and the unit's ability to perform the necessary functions. First, for the different kinds of relationships in the unit, the DENSITY of links that are present in a given network will reflect the overall level of that kind of interaction in the team. Since it is to be expected that not all of the unit members have interactions of a given kind for every other member in the unit, the average deviation from the mean level of communication (IN-DEGREE VARIANCE) will be used as a measure of the degree to which a given kind of communication tends to be directed to only a few members or spread evenly throughout the unit.

On the other hand, some of the members will have mutual links between them, reinforcing their ability to exchange both their perspective on the problem and their resources. That is to say, for a given pair of individuals, a link may exist such that one of them will frequently approach the other for a given kind of exchange. If this happens in both directions (which is not necessarily the case), then both members will benefit from that interaction, and this will be reflected in the likelihood of their achieving progress in the solution of the problem. Thus, another way to measure the efficiency of the network will be to consider the number of RECIPROCAL links, relative to the uni t's size.

Finally, indirect links will also be a network property with a strong effect on performance. Two networks of the same size may have the same initial density (the average number of links per member, relative to the unit's size). However, when indirect links are also considered, those networks where members tend to be both receivers and providers of a given resource will show a gain in density that may be very different from that shown by networks where a relatively large proportion of members are exclusively receivers of the given resource. Thus, the GAIN IN DENSITY when indirect links are considered as well as direct ones will also be a measure of the unit's ability to maintain an adequate flow of resources within itself.

3. Method.

A cross-sectional sample survey of 223 R&D teaas froa different industries was aade as part of a research project dealing with patterns of interaction and foras of organization in industrial research units. The survey included three types of questionnaires, one to be filled out by every unit aeaber and the unit leader, one suppleaentary questionnaire to be filled out by the unit leader and the unit aanager (if there was one), and one to be filled out by at least two senior aanagers responsible for the foraal evaluation of the teaa.

In each organization, units were selected and questionnaires for each unit were distributed to aeabers, leaders, and aanagers by coapany officials. In order to insure confidentiality, questionnaires were returned to the saae coapany officials in sealed envelopes. Adalnistration of the questionnaire included the preparation of a roster sheet for each teaa. In these rosters each unit aeaber's naae was associated to a nuaber that served as the basis for answering several kinds of socioaetric questions. For each of four kinds of relationships, there were two questions: one of thea was of the fori "I frequently approach these people for technical assistance or guidance", followed by a row of nuabered cells in which the respondent would aark those that identify unit aeabers according to the roster sheet. The other question was of the fora: "These people frequently approach ae for technical assistance or guidance", again followed by a row of nuabered cells. Other socioaetric iteas in the saae foraat dealt with different types of interaction in the unit. Including "inforaation exchange", using each other as "sounding board" for the developaent of new ideas, and "consultation for planning" their own activities. Using the roster sheet, aeabers identified those other researchers whoa they approached for the given kind of exchange and those who approached thea for the saae purpose.

Network properties were aodeled with the aid of graph-theoretic concepts and aeasured through coaputations based on the adjacency aatrices that represent the networks (See Holland and Leinhardt 1978). First, the overall level of interaction in the unit was aeasured by its choice DENSITY. It represents the degree to which unit aeabers have been able to establish coaaunication links aaong theaselves.

Second, within each unit we cannot expect all of the aeabers to have the saae nuaber of links to other aeabers (whether to provide thea with, or to receive froa thea a given kind of resource). In-Degree Variance (the average deviation of the coluan suas froa the aean nuaber of links per aeaber) was used as a aeasure of the degree to which coaaunication is directed toward a relatively saall subset of teaa aeabers froa the rest. That is to say, this aeasure is an indicator of the degree to which, in the given unit, relatively few of the aeabers are approached by others for a given kind of exchange.

Third, the average number of reciprocal links per member (the number of reciprocal links in the unit, divided by the unit's size), represents the degree to which relationships in the unit are such that a given resource may flow both ways (both members in a dyad can benefit from each other's resources).

Finally, it is reasonable to think of an Indirect link between members (A provides technical assistance to B, and B in turn provides the same kind of assistance to C) as having also an important role in the diffusion of the resources available to the unit. Under this assumption, we have computed the the two-step choice density for every team on the basis of the adjacency matrix of indirect links. Structural properties of the communication networks are such that networks with the same initial density and the same number of reciprocal links may still differ widely in their two-step density and number of indirect links. Therefore, the gain in density from the simple to the two-step adjacency matrix was computed for each team as a measure of the unit's network efficiency in indirectly capturing a given resource from, or indirectly making it available to, its different parts.

Performance was measured through productivity and innovativeness ratings obtained from three different sources: the unit members themselves, the unit leader, and at least two senior managers responsible for the formal evaluation of the unit. The corresponding questionnaires included items that asked for the member's, the leader's, or higher management's evaluation of the unit's productivity and of the unit's innovativeness. Answers were provided on a seven-point scale from "highly productive (or highly innovative)" to "Not at all productive (or innovative)".

Using three separate measures as dependent variables helps in discriminating associations that may reflect real differences in performance evaluation from associations that could be due to "halo effects" (the level of communication activity influencing the members' evaluation of the unit's productivity, for example). Specifically, external (senior manager) evaluations are not likely to be influenced by the level or quality of communication within the unit, but rather by differences in performance detectable from outside the unit. Thus, since evaluation from the three different sources considered would tend to be based on at least slightly different criteria, if a network structural characteristic shows a consistent association with all three of them it is more likely to reflect a more objective difference in team characteristics.

4. Resul18.

The sample obtained included 223 teams from twenty eight different companies. Industries represented were pharmaceutical, automobile, consumer goods, aerospace, electronics, oil, genetic engineering, and chemical; teaas in the sample also represent basic, applied, and development research. The size of the teams ranged from three to thirty three members, with an average of about eight. A remarkable return rate of 91Z was obtained for the sample, mainly due to the fact that the survey was directed to all members of each team, and because of the help of participating company officials.

For each unit, sociometric choices were represented in an adjacency matrix that avoided self-choices and included only "acknowledged" choices (an acknowledged choice is one in which member A claims to approach member B for a given kind of exchange AND member B claims that, in fact, he is approached by member A; this is distinct from the fact that member B may also claim to approach member A, in which case we say that the choice is "reciprocated"). In order to avoid a bias in the analysis that would result from a large proportion of members missing in a team (since choices which referred to them would not be acknowledged), those cases where more than 2SZ of the members either did not return the questionnaire or returned it unanswered were dropped, leaving a sample of 190.

Since most of the network properties present a series of effects related to the size of the teams, the net association between structural and dependent variables was calculated as a set of partial correlations where unit size was controlled for. Table 1 shows Pearson correlation coefficients between technical assistance network properties and productivity ratings. Overall, measures of the properties of Technical Assistance networks that enable the unit to increase the flow of its resources are strongly associated ith all three measures of unit performance (those provided by unit members, the unit leader, and higher management). Correlations with performance evaluations given by higher management were the lowest, but still highly significant statistically.

Table 1: Partial Correlations (Controlling for Unit Size) Between Technical Assistance Network Properties and Performance (Productivity) Ratings (N-190)

STRUCTURAL PROPERTIES / PERFORMANCE RATINGS:	UNIT MEMBERS	UNIT LEADER	HIGHER MANAGEMENT
DENSITY	.31	.24	.20
IN-DEGREE VARIANCE	.21	.18	.21
RECIPROCAL LINKS	.17	.23	.17
GAIN IN DENSITY	.19	.18	.14

p<.05-.12; p<.01*.17

The differentiation of a core of unit members that is approached by the rest for technical assistance (as indicated by the unit's

In-Degree Variance) is also consistently associated with better performance ratings, and the same is true for the Gain in Density, or the ability of the unit to maintain the flow of resources through indirect links.

For the network of relationships in which members use each other as "sounding board" for developing new ideas, the dependent variable is innovativeness, rather than productivity ratings. Table 2 shows correlation coefficients between structural properties of the "sounding board" network and innovativeness performance ratings. In this case, not all properties have a significant association with better innovative performance across ratings. For example, Density, by Itself, is not closely associated with performance evaluations given either by the unit leader or higher management.

For this network, the number of RECIPROCAL links in the unit has the lowest association with the members' evaluation and is not significantly associated with either the leader's or higher management's; on the other hand, IN-DEGREE VARIANCE and GAIN IN DENSITY show remarkable association with ratings provided by both members and leader of the unit.

Table 2: Partial Correlations (Controlling for Unit Size) Between "Sounding Board" Network Properties and Performance (Productivity) Ratings (N-190)

STRUCTURALX PERFORMANCE PROPERTIES ¥ RATINGS:	UNIT MEMBERS	UNIT LEADER	HIGHER MANAGEMENT
DENSITY	.25	.07	.11
IN-DEGREE VARIANCE	.28	.17	.08
RECIPROCAL LINKS	.19	.06	.07
GAIN IN DENSITY	.25	.18	.06

p<.05*.12; p<.01-.17

Table 3 shows partial correlation coefficients between structural variables of the Information Exchange network and productivity ratings. In this case, properties associated with better evaluations are DENSITY and the number of RECIPROCAL links, both with respect to the leader's and the members' evaluation. Highest correlations are for DENSITY with respect the members' evaluation, and the number of RECIPROCAL links with respect to the leader's rating. For this network, the only structural property that is significantly associated with management evaluations is DENSITY.

Table 3: Partial Correlations (Controlling for Unit Size) Between Information Exchange Network Properties and Performance (Innovativeness) Ratings (N-190)

STRUCTURAL¥ PROPERTIES ¥	PERFORMANCE RATINGS:	UNIT MEMBERS	UNIT LEADER	HIGHER MANAGEMENT
DENSITY		.25	.17	.13
IN-DEGREE VARIANCE		.15	.12	.03
RECIPROCAL LINKS		.18	.20	.05
GAIN IN DENSITY		.17	.13	.08

p<.05-.12i pC.01-.17

6. Conclusion.

The utility of using theoretical insights from the sociology of organizations is supported by results shown, based on the model used for this study. Indeed, even though the abstract nature of the model is a necessary condition in its development, statistical results like those shown here indicate that useful Implications for research management may be derived from these studies.

First, it is important to realize that research units present complex communication structures that involve several different kinds of relationships. The fact that two members are able to exchange Information does not guarantee that that same relationship will be useful for developing new ideas of tackling a difficult technical problem.

Also, at the unit level, properties of the communication networks influence the unit's ability to bring together both task requirements and resources available, which itself will have a strong influence on performance. These properties may be different even for the various kinds of networks present in the same unit. Furthermore, for different kinds of networks, it is different structural properties that show a closer association with performance. For example:

- For the technical assistance network, most of the structural properties have a close association with all three sources of evaluation; however, this is not true for relationships in which new ideas are developed, or where only information exchange takes place.

- For the technical assistance and the sounding board networks, the presence of a relatively small subset of members that are approached by the rest in order to obtain technical assistance or guidance, or in order to enlist their help in the development of new ideas, is closely associated with both the leader's and the members' evaluation; this is not true for the information exchange network, where only the number of RECIPROCAL links is similarly associated with ratings received. Thus, it may be seen also that different structural properties are relevant, depending of the kind of network considered.

- The fact that for the "sounding board" relationship, both Gain in Density and Xn-Degree Variance are consistently associated with performance evaluations given by both unit members and leader may mean that team will be more innovative if ideas in it may reach a central group in the unit, even if it is only indirectly, rather than having a high number of relatively loose-structured idea-generating relationships.

On the other hand, management's evaluations show the lowest association with most of the structural variables for all the networks, but in the case of the technical assistance network they are still statistically significant. Indeed, the fact that members' ratings are the ones that show the highest degree of association with structural properties of the communication networks may be indicative that their evaluations are likely to be subject to a "halo" effect: their evaluation of the unit's productivity or innovatlveness is highly dependent on the amount of interaction they perceive as taking place in the unit.

Under this argument, however, the fact that structural properties of the technical assistance network are highly associated with management's evaluations underscores the importance of considering the right kinds of interaction when trying to account for differences in unit performance.

Under the assumptions of the model used here, different kinds of interaction have different instrumental value for the research activity, and, for each kind of network, different structural properties will show different degrees of association with performance ratings. Evidence presented here not only supports these claims, but it also directs attention to the complex set of social phenomena that must be examined at the unit level of analysis in order to understand the research process as it takes place in organizational settings.

B I B L I O G R A P H Y

Allen, Thomas, *Managing the Flow of Technology*, Cambridge: M.I.T.
1977 Press.

______, "R&D Performance as a Function of Internal
1980 Communication, Project Management, and the Nature of the Work," *IEEE Transactions on Engineering Management* (EM-27) 1:2-12.

Blau, Judith R., "Patterns of Cummunication among Theoretical High
1974 Energy Physicists," *Sociometry*. (37), 3:391-406.

"Scientific Recognition: Academic Context and
1976 Professional Role," *Social Studies of Science*. (6):533-45.

"Sociometric Structure of a Scientific Discipline,"
1978 in *Research in the Sociology of Knowledge, Science and Art*. Vol. 1:101-206.

Brieger, R., "Career Attributes and Network Structure: A Blockmodel
1976 Study of a Biological Research Specialty," *American Sociological Review*, (41):117-35.

Crane, Diana, *Invisible Colleges: Diffusion of Knowledge in*
1972 *Scientific Communities*, Chicago: University of Chicago Press.

Fischer, W.A., "Scientific and Technical Information in the
1980 Performance of R & D Groups," *TIMS Studies in the Management Sciences*, (15):67-89.

Fischer, W.A., and Rosen, B., "In Search for the Latent Information
1982 Star," *R&D Management*, (12)2:61-6.

Friedkin, N.E., "University Social Structure and Social Networks
1978 among Scientists," *American Journal of Sociolgy*, (83): 1444-65.

Frischauth, D.S., and Allen, T.J., "A Model for the Description and
1969 Evaluation of Technical Problem Solving," *IEEE-Transactions on Engineering Management* (EM-16):58-64.

March, J.G., and Simon, H.A., *Organ!zations*, New York: John Wiley and
1958 Sons, Inc.

Price, D.J. deS. and Beaver, L., "Collaboration in an Invisible
1965 College," *American Psychologist*, (21):1011-18.

Tushaan, M.L., 1977 "Special Boundary Roles in the Innovation Process,' Administrative Science Quarterly, (22): 587-605.

1978 "Technical Communication in R & D Laboratories: The Impact of Project Work Characteristics," Academy of Management Journal. (21)4:624-45.

1979 "Impacts of Perceived Environmental Variability on Patterns of Work Related Communication," Academy of Management Journal, (22)3:482-500.

Tushman, M.L., and Nadler, D.A., 1980 "Communication and Technical Roles in R&D Laboratories: An Information Processing Approach," TIMS Studies in the Management Sciences (15):91-112.

Zuckerman, H., 1967 "Nobel Laureates in Science: Patterns of Productivity, Collaboration and Authorship," American Sociological Review, (32):391-403.