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Information Flow in Research and Development Laboratories

Technical communication patterns in two research and development laboratories were examined using modified sociometric techniques. The structure of technical communication networks in the two laboratories results from the interaction of both social relations and work structure. The sociometric "stars" in the technical communication network who provide other members of the organization with information either make greater use of individuals outside the organization or read the literature more than other members of the laboratory.

No research and development laboratory can be completely self-sustaining. To keep abreast of scientific and technological developments, every laboratory must necessarily import information from outside. There are two obvious ways of doing this. The literature can be used by each member of the laboratory staff to keep informed about recent developments in his field; or knowledgeable people outside the laboratory can be consulted for this purpose.

Several recent studies have shown, however, that the average engineer makes little or no use of the scientific and professional engineering literature (Berul, *et al.*, 1965; Allen, 1966) and, furthermore, that there is a consistent inverse relation between the performance of industrial and governmental engineers and scientists and the extent to which they use people outside of their organization as sources of information (Allen, 1964 and 1966; Schilling and Bernard, 1964). There is equally consistent evidence, however, of a strong direct relation between intraorganizational communication and performance (Allen, 1964; Allen, Gerstenfeld, and Gerstberger, 1968; Schilling and Bernard, 1964).

It is probably safe to say that poor performance is not due directly to any negative contribution from the information source itself. Rather, it is lack of information, which prompts the use of an information source and which is the underlying cause of poor performance when information is not supplied by the source. Consultants within the laboratory appear to be better able than external consultants to fulfill this need for information.

Hagstrom (1965) found a strong positive relation between performance and extraorganizational communication. In his study, however, the organization (an academic department) occupied a subsidiary position to a more inclusive social system, the "invisible college" or academic discipline. Although the communication process was external to the academic department it was *internal to the academic discipline.*

The concept of a shared coding scheme (Katz and Kahn, 1966) offers a rather simple explanation for the differences between industrial and academic situations. Scientists in academic institutions do not have schemes for perceiving and ordering the world that are peculiar to their academic institutions. They feel aligned with scientists who share their particular research interests regardless of their organizational affiliation, and these invisible colleges mediate their coding schemes. In industrial and governmental laboratories, however, the organization is of primary importance to its members. The organization demands a degree of loyalty and affiliation far outweighing that required by academic departments; and mutual experience and schemes of ordering the world that are bureaucratically imposed are characteristic of the organization and can be quite different from the schemes of members of their particular discipline in other organizations.

The existence of different coding schemes in different organizations introduces the possibility of mismatch and attendant difficulties in communication between organizations. The mismatch problem is compounded when incompatibilities between two coding schemes go unrecognized. Allen (1966) suggested mismatching as the explanation for the observed inverse relation between extraorganizational communication and performance. It is possible that this mismatch can be reduced by key individuals who are capable of translating between two coding schemes either through personal contact or knowledge of the literature, and who can act as bridges linking the organization to other organizations and workers in the field. Such individuals are possible sources for the transmission of information.

The present paper[1] is concerned with the flow of technological and scientific information both into and within the research and development laboratory. The contrast in the performance of internal and external consultants led to hypothesizing the existence of special routes through which technical information most effectively enters the laboratory. Based on studies of mass communications (Lazarsfeld, Berelson, and Gaudet, 1948; Katz and Lazarsfeld, 1955; Katz, 1960; Coleman, Katz, and Menzel, 1966), the existence of a two-step process was hypothesized, through which the average engineer was connected by an intermediary to information sources outside of his laboratory. If special routes exist, it would be important to know what determines their structure; therefore an investigation was made of factors that might influence the structure of each of three forms of technical communication networks.

Hypotheses

Two major hypotheses were generated, based upon the findings of earlier studies in mass communication and upon other research on information flow.

1. *Influence of organization structure.* The structure of the technical communication network of the laboratory will be significantly influenced by two factors:

 a. The structure of the formal organization; that is, the pattern of formal organizational relationships in the laboratory.

 b. The structure of the informal organization; that is, the pattern of friendships and social relations among members of the laboratory.

2. *Technological gatekeepers.* Individuals who occupy key positions in the communication network of the laboratory; that is, those to whom others in the laboratory most frequently turn for technical advice and consultation, will show more contact with technical activity outside of the laboratory:

 a. They themselves will be better acquainted than others in the laboratory with such formal media as the scientific and technological literature.

 b. They will maintain a greater degree of informal contact with members of the scientific and technological community outside of their own laboratory.

RESEARCH METHODS

This study was conducted in two research and development organizations: Laboratory A, a department with 48 employees in a medium-sized (approximately 5,000 employees) aerospace firm. Thirty of the 48 members of this department returned questionnaires. This is an extremely poor response for a sociometric study, and the data would not be reported, except that they add an interesting supplement to the findings in the second organization.

Laboratory B was relatively small and self-contained, and actively engaged in work on new materials and devices in the fields of direct energy conversion and solid-state electronics, for both military and industrial applications. The data were collected from 28 of the 34 professional members of the laboratory by means of written questionnaires followed by brief personal interviews.[2]

Sociometric Relations

Four questions were asked of each respondent. One of these dealt with the social relations within the laboratory; the other three provided indications of the routing of technical informa-

[1] This research was supported by grants from the Office of Science Information Service, National Science Foundation (GN353 and GN597). Data analysis was performed, in part, at the M.I.T. Computation Center. Peter G. Gerstberger, Milton L. Lavin, and Paul W. O'Gara provided assistance in the data analysis. The authors gratefully acknowledge the cooperation of the management and employees of the two laboratories.

[2] Examination of resumés for the six nonrespondents revealed no striking differences between these and the other laboratory members. One of the six held a Ph.D. Two had been just recently employed by the laboratory, and explained that they were not well enough acquainted with other members to complete the questionnaire in a meaningful manner. Of the remaining four nonrespondents, one was out of town at the time, and the other three had an aversion to questionnaires.

tion through the organization. In laboratory B, additional questions dealt with individual information-gathering behavior, including questions on technical reading habits, amount of technical discussion, and contact with members of other organizations.

Figures 1 and 2 illustrate the pattern of two sets of relationships among the members of laboratory B. In Figure 1, the arrows indicate the direction of choices in social contact; Figure 2 shows the pattern of choices for technical discussion. Figure 1, showing the choices between Ph.D.'s and non-Ph.D.'s shows only three social contacts directed toward the non-Ph.D.'s (Figure 1b), whereas five of a total of nine choices are directed toward the Ph.D. group (Figure 1a); but in only two cases, subjects 24 and 28, is the choice reciprocated.

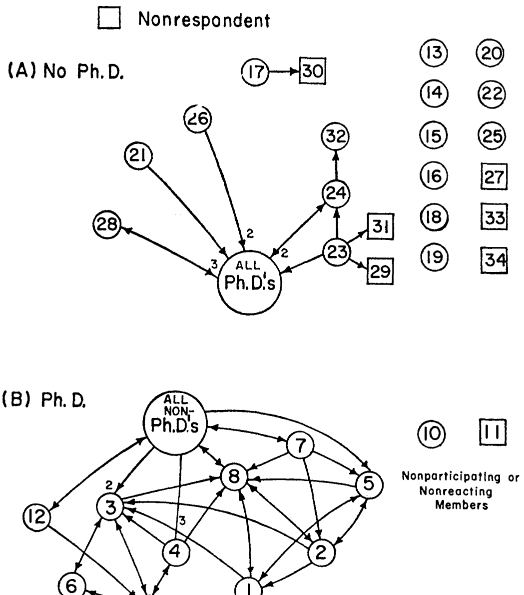

FIGURE 1. CHOICES FOR SOCIAL CONTACT IN LABORATORY B. (Numbers 1 and 2 in circles represent the research directors; numbers at arrowheads indicate number of connections where more than one.)

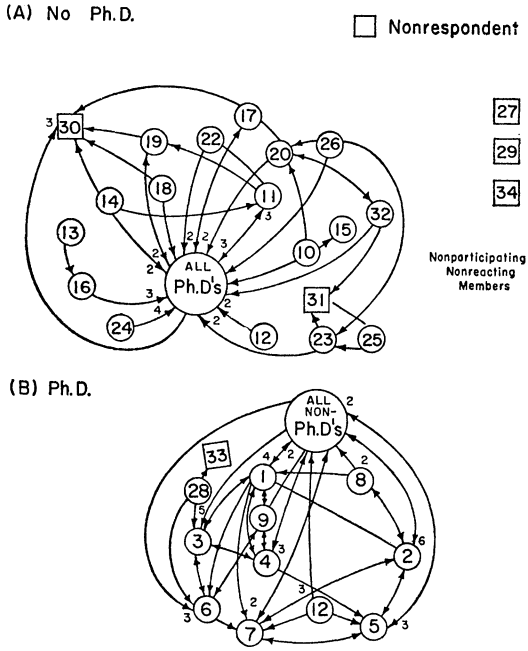

FIGURE 2. CHOICES FOR TECHNICAL DISCUSSION IN LABORATORY B. (Numbers 1 and 2 in circles represent research directors; numbers at arrowheads indicate number of connections where more than one.)

Sociograms were compared for two or more types of choice (e.g. technical discussion and socialization), by comparing the degree of overlap between the two actual networks with the amount of overlap that would be expected under chance conditions. The number of overlapping choices expected by chance will vary as a function of the number of sociometric choices made by each individual. For example, if every individual in the laboratory chose five others for socialization and five for technical discussion, there would be expected, by chance, a greater number of overlapping connections in the two networks than would be expected if each person had chosen only four others. The expected number of overlaps was computed for each person who returned a questionnaire. This expected number was based on a binomial probability model in which the probabilities of overlap and nonoverlap are a function of the number of actual choices made by each individual respondent. The problem is directly analogous to the classical birthday problem (Feller, 1950: 31–32), except that each individual is allowed to have several "birthdays" (e.g., four), and the number of days in the year is set equal to the size of the organization (34) from which the choices are made. The probabilities of overlaps expected at random for a respondent choosing four other persons for socialization and five for technical discussion are:

Number of choices common to both relations	0	1	2	3	4	5
Probability of occurrence	0.02	0.24	0.48	0.24	0.02	0

Expected values for the total sample are obtained by summing all of the individual values. The observed distribution of overlaps is then compared with this expected distribution by means of a one-sample Kolmogorov-Smirnov test. In Figure 3, the bar graphs show the observed number of overlapping choices and the number predicted by the random model.

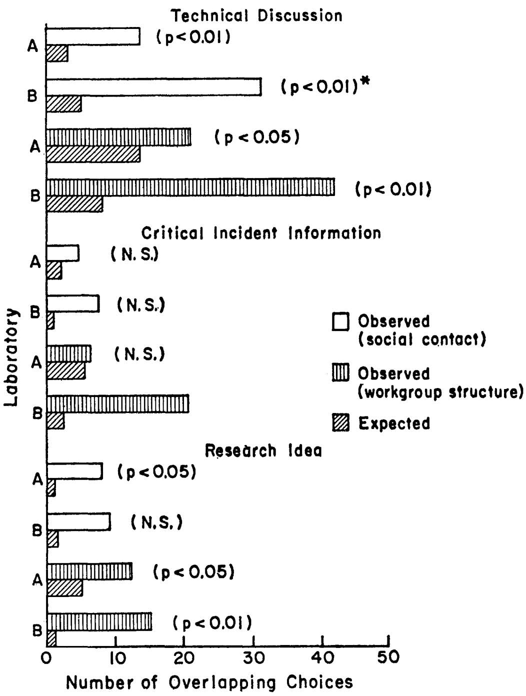

FIGURE 3. NUMBER OF OVERLAPPING CHOICES BETWEEN THE SOCIAL CONTACT AND WORK GROUP STRUCTURE AND THREE NETWORKS OF TECHNICAL INFORMATION FLOW IN RESEARCH AND DEVELOPMENT LABORATORIES A AND B. (*Determined by Kolmogorov one-sample test; N.S.: difference not statistically significant.)

RESULTS AND DISCUSSION

Relationship among Choices

Figure 3 compares three communication-oriented choices with the socialization choice. There is strong relationship in the selection of individuals for socialization and the selections of those for technical discussion in both laboratories. In laboratory B, this is due only partially to the rather tight clique found among the Ph.D.'s in the laboratory. As a matter of fact, among the Ph.D.'s alone, the amount of overlap is not significantly above chance. The networks for critical incident information and for new research ideas show a decidedly weaker relation to the socialization network in the laboratory. Only in the communication of new research ideas in laboratory A is the observed amount of overlap significantly above chance expectation. The informal organization is then strongly related to the technical discussion network, but is far less influential in determining the flow of critical ideas, or of ideas for new work. Its relation to communication is limited to the general information flow that occurs during technical discussions. Nevertheless, technical discussions among colleagues are certainly an important general device for transferring technical information. Although it is impossible from such data as these to determine the direction of the causal link; that is, does socialization bring about transfer of technical information, or do people socialize more with those with whom they like to discuss technical problems, it appears that the informal organization of the laboratory occupies an important position in the transfer of information.

The question now remains of the impact of formal organizational structure upon communication. In laboratory A, organizational relationships were taken directly from the departmental organization chart. The work group was considered to consist of a first-line supervisor and those reporting to him. In laboratory B, no organization chart existed. Since its organization was quite flexible and revolved around a number of long-term and short-term projects under the direction of two research directors, consideration of formal structure was restricted to *ad hoc* project groups. The respondents in laboratory B were asked to name "The people whom you consider to be members of your present work group." In both laboratories, the amount of observed overlap between the social-contact network and the formal organizational structure was far from being statistically significant; therefore they appear somewhat independent and should exert independent influences on information flow.

The relation between formal organization and technical communication is much stronger (Figure 3) than was evident in the case of informal organization. Work-group structure influences not only technical discussion but the flow of new ideas, and in laboratory B critical ideas as well. Here there is no doubt about the direction of causality. If two people are closely related organizationally, they will be more likely to discuss technical problems and possibly even more likely to provide each other with critical research information. In the case of transmitting new research ideas, it is obvious that an individual with an idea for a new research project will first express that idea to his immediate supervisor.

Controlling for the effects of the formal organization, by comparing only those social and technical discussion links external to each individual's work group produces a somewhat weaker, but still significant, relationship than that found when work group members were included. The formal organization is therefore the more important, but not the sole determinant of the structure of the technical communication network of the laboratory.

Influence of Status on Communication

Several studies (Hurwitz, Zander, and Hymovitch, 1960; Newcombe, 1961) have shown that the presence of prestige or status hierarchies in a social system will affect the flow of information. Individuals of high status will tend to like one another and to communicate frequently; individuals of low status will neither like one another as much nor communicate as much. Furthermore, lower-status members of the social system will direct most of their communication toward the higher-status members, without complete reciprocation.

The communications and social-contact networks in laboratory B provide almost perfect examples of these relationships. Figures 1 and 2 show the influence of a status differential (in this case exemplified by possession of the doctorate degree) on the communication network in the laboratory.[3] The Ph.D.'s apparently communicate quite freely among themselves, but they seldom socialize or discuss technical problems with the non-Ph.D.'s. This could, of course, impede organizational performance, but an even more serious effect is evident. The non-Ph.D.'s in the laboratory scarcely ever socialize with one another and they discuss technical problems among themselves far less than their Ph.D. colleagues. Furthermore, the non-Ph.D.'s direct most of their socialization (64 percent) and technical discussion (60 percent) to Ph.D.'s. The Ph.D.'s, in contrast, direct only 6 percent of their socialization and 24 percent of their technical discussion to non-Ph.D.'s.

The tendency of the lower-status members of a dichotomous hierarchy to direct their communications upward has been explained by Kelley (1951) as a form of substitute upward locomotion. "Communication serves as a substitute for real upward locomotion in the case of low-status persons who have little or no possibility of real locomotion." Kelley points out, however, that this statement holds true only for those low-status persons who show some desire to move upward. Cohen (1958) has replicated these results with another experimental group, and finds further that one form of upward communication (conjectures about the nature of the higher-status job) increases both when locomotion is desired but not possible and where it is possible but not desired.

In laboratory B, upward mobility is highly desired but, in the short run, impossible. It is therefore not surprising that the non-Ph.D.'s should attempt to enhance their own status through association with the higher-status members of the laboratory. In an organization in which both Ph.D.'s and non-Ph.D.'s work together on the same tasks, the most rewarding experiences: publication, recognition, etc., tend to be restricted to those holding the advanced degree. The non-Ph.D.'s are therefore resigned to gaining reflected glory as satellites of the higher-status group, and tend to avoid association with their lower-status colleagues.

Information Habits and Communication Choices

Figure 2 shows very clearly that some individuals are much more frequently chosen than others for technical discussion. These frequently chosen individuals, or sociometric "stars," were cited as sources of critical in-

[3] Since there were only two Ph.D.'s in laboratory A, the relationship was not apparent there.

cident information. (This analysis was performed in laboratory B only, because although there were stars in laboratory A, nothing is known of their information-gathering behavior. It was not possible to obtain data on the information-gathering behavior of leaders and a matched sample of non-stars.) They may well be key links between the internal information network of the laboratory and the scientific and technological communities outside of the laboratory. To examine this possibility, the "stars" in two sociometrically determined information networks were compared with their colleagues to determine whether they showed any systematic differences in their information-gathering behavior. Specifically, it is hypothesized that the stars will make greater use of such sources as literature and professional friends outside the organization; in other words, that they will act as "technological gatekeepers."

The eight respondents most frequently chosen for technical discussion, (the number of times that is at least one standard deviation above the mean for the laboratory; that is, six or more), have more exposure both to the literature and to oral sources outside of the laboratory than the average professional in the laboratory (Table 1).

Both research directors are included among the eight "stars." This was at first surprising, since the question asked was directed at the discussion of purely technical questions and should have excluded administrative and organizational standing. Both were apparently very competent technically, however, and were included among the seven individuals who were cited as sources of critical incident information, and were between them responsible for all of what the respondents almost unanimously agreed were the four best technical ideas that anyone in the laboratory had had in the previous years. Eliminating the two research directors from the analysis in Table 1, does not significantly change the results (for professional friends outside the laboratory, $p = 0.11$; for the reading of professional and scientific periodicals, $p = 0.0001$).

When requested to indicate the source of any information which influenced the course of their most recently completed research projects, twelve respondents cited seven other individuals within their own laboratory as the source of such information. In Table 1, these seven people are compared in terms of their own information-gathering behavior in the same manner as were the technical discussion stars.

TABLE 1. COMMUNICATION BEHAVIOR OF INDIVIDUALS AT KEY POSITIONS OF TECHNICAL COMMUNITION NETWORK.*

	Number of technical discussion choices		Source of critical incident information	
Communication characteristics of personnel	6 or more ($N = 8$)	4 or fewer ($N = 20$)	Yes ($N = 7$)	No ($N = 21$)
Use of personal friends outside the laboratory as sources of information	64	25†	67	30†
Use of technical specialists within the laboratory as sources of information	50	40	57	40
No. of technical periodicals read	88	40‡	100	45‡
No. of professional and scientific periodicals read	75	35§	86	35§

* Numbers in table represent percentage above the median.
† $p < 0.10$.
‡ $p < 0.05$.
§ $p < 0.001$ Mann-Whitney U-test.

This contrast is especially pronounced in the case of scientific and professional literature; that is, journals published under sponsorship of scientific and engineering societies.[4] Again there is the pattern of greater contact with experts outside of the organization and more exposure to the literature.

There were therefore two classes of individ-

[4] The names of all technical periodicals to which each respondent subscribed or read regularly was obtained, and those sponsored by engineering and scientific societies were separated out in the analysis.

uals in laboratory B. The majority had few information contacts beyond the boundaries of the organization. A small minority had rather extensive outside contacts and served as sources of information for their colleagues. There is then evidence of a two-step flow of information, in which about six individuals act as technological gatekeepers for the rest of the laboratory.

The gatekeepers themselves showed some variation in the type of information sources they used. Some relied more upon the literature while others relied more on oral sources. A comparison of relative exposure to technically oriented friends outside of the organization and to the scientific and professional literature shows a slight positive correlation (Kendall tau $= 0.27$), but the relation does not approach statistical significance ($p = 0.21$).

DISCUSSION

Individual gatekeepers use different sources of information: some transmit late information from the literature, others, from oral sources.

They may also differ in how their information is applied, but this possibility cannot be tested with the present data. In mass communication research, (Katz and Lazarsfeld, 1955) opinion leaders were found to be differentiated by topic; those who were influential in public affairs were not necessarily influential in determining fashion patterns. Moreover, the area of influence was related to media exposure; public affairs leaders read more news magazines and fashion leaders more fashion magazines. Thus, the content of the messages processed by the various gatekeepers in research and development laboratories should be examined in more detail. The selection of literature or oral sources by gatekeepers may be based upon the kind of information in which the gatekeeper specializes; and the sources may vary in their ability to provide different types of information. For example, there is evidence to suggest that the literature provides general information about the status of a technological field, while oral sources provide more detailed information about particular techniques (Menzel, 1966; Scott, 1959; Goodman, Hodges, and Allen, 1966). Gatekeepers who specialize in the state-of-the-art should tend to read, while those specializing in particular techniques should tend to talk to external sources.

There does not appear, as yet, to be a way to identify gatekeepers on an a priori basis. It is quite clear, however, that they are important contributors to the efforts of the laboratory. In both laboratories, the gatekeepers held significantly more patents, had published significantly more papers than their colleagues, and tended to be first-line supervisors (two-thirds of the gatekeepers are first-line supervisors in laboratory A, and the two research directors in laboratory B). Gatekeepers were more frequently Ph.D.'s in laboratory B, and one of the two Ph.D.'s in laboratory A was a gatekeeper.

Does an individual become a gatekeeper because he occupies a managerial position, or does his promotion to management result, in part, from his contribution as a gatekeeper? Holding a managerial position certainly provides an individual with easier access to people outside his organization, but it is hardly likely to stimulate his technical reading. If promotion to a supervisory position is a reward for technical communication, it may be self-defeating strategy. It places the man in a position in which his next promotion will be to block his effectiveness as a transmitter of technical information. The second promotion will probably remove him too far from the technical work to allow him to remain current in technical information, and will impose an administrative separation between himself and the average engineer. This can be seen in laboratory A, where the department head was two organizational levels above the engineers and was not considered a gatekeeper.

There are two further implications for management. First, the factors which influence the flow of technical information should be understood, since some of them are under management's control and can be used to improve the communication system. Second, the value of gatekeepers should be recognized. Research management often fails to make effective use of these individuals. One obvious first step is to ease their access to outside sources through such devices as paid attendance at professional meetings and liberal travel budgets. In addition, they should be allowed easier access to the literature. To minimize cost in providing access to search and retrieval systems, such access should be given first (and perhaps solely) to the technological gatekeeper. Making adequate use of them may allow a drastic reduction in the number of entry points required to any automated literature retrieval system.

Furthermore, recognition and reward for performance as transmitters of information will ensure that gatekeepers continue in that capacity. Management presently appears either to discourage this activity by failing to reward it, or to reward the gatekeeper by promotion and thereby make it impossible for him to continue as a transmitter of information.

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