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ABSTRACT

Data from a large number of recent research studies are brought to bear on the problem of providing for the technical information needs of research and development projects. The importance of proper support by the technical staff is shown, and it is argued that the best way to couple the project team to information sources outside the organization is by an indirect route through key personnel among the laboratory's technical staff. Informal relations and physical location are shown to be important determinants of the structure of organizational communication networks. Informal relations can be developed through formation of project teams and inter-group transfers and loans. The effect of physical location on communications is especially strong and should be given serious consideration when designing research facilities. (Author)

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# MEETING THE TECHNICAL INFORMATION NEEDS OF RESEARCH AND DEVELOPMENT PROJECTS

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# ABSTRACT

Data from a large number of recent research studies are brought to bear on the problem of providing for the technical information needs of research and development projects. The importance of proper support by the technical staff is shown, and it is argued that the best way to couple the project team to information sources outside the organization is by an indirect route through key personnel among the laboratory's technical staff.

Informal relations and physical location are shown to be important determinants of the structure of organizational communication networks. Informal relations can be developed through formation of project teams and intergroup transfers and loans. The effect of physical location on communications is especially strong and should be given serious consideration when designing research facilities.

Previous papers in this symposium have dealt with the processing of information required for the management and control of research and development projects. We turn now to the handling of a very different type of information. Technical information, derived from scientific or technological investigation is the very lifeblood of the research and development project. It is different in many ways from administrative information and these differences impose severe constraints on the manner in which it can be effectively processed and transmitted.

## The Problem with Technical Information

To date, attempts to automate the transmission of scientific and technological information have been most notable for their failure. The reason for this does not lie in any lack of attention or inadequate effort allocated to the problem, since very large sums of money have been expended on storage and retrieval systems for scientific and technological information. Rather, it is due to the nature and complexity of the information, itself, and to the uncertainty and very personal nature of each user's needs.

## The Importance of Communication Between Projects and Supporting Staffs

For the very same reasons that make automation of technical information processing so difficult, the human being has become the most effective source of this information. Communication with a technically competent colleague is conducted on a two-way basis, with the output of the source tracking and responding to the expressed needs of the user. In this manner, the source's flexibility and its ability to rapidly response to communicated needs enables it to effectively cope with the uncertain nature of those needs. The advantage of the human information source over competing channels is reflected in the results of a number of recent investigations (Allen, 1966; Auerbach, 1965; North American Aviation, 1966) which show very clearly that organizational scientists and engineers rely most heavily upon other scientists and engineers to fulfill their information needs. Furthermore, because he is better able to understand the user's requirements and can communicate his own ideas more effectively to the user, technical colleagues who are also members of the user's organization are the most effective of all human information sources. A large number of recent studies (Allen, 1964; 1966; Baker, et.al., 1967; Pelz and Andrews, 1966; Shilling and Bernard, 1964) show that increased use of organizational colleagues for information is strongly related to scientific and technological performance. The relation to performance is, perhaps, demonstrated most clearly in a recent study (Allen, et.al., 1968 ) by a group at M.I.T. Some of the results of this study will now be presented to form a basis for a discussion of strategies for properly structuring the flow of technical information in research and development organizations.

## The Internal Consulting Study

Eight pairs of individuals in different organizations, but working on identical problems, were compared on the extent to which each of them consulted with organizational colleagues. Since there were always two individuals attempting to solve the same problem, their solutions could be compared for relative quality and then the sample can be split between "high" performers and "low" performers. Performance evaluations were made by competent technical evaluators in the government laboratories that had sponsored the projects. Dividing the sample into high and low performers allows a further comparison to be made, now on an aggregate basis, of behaviors leading to high or low performance.

When such a comparison is made with respect to the number of times organizational colleagues were consulted during the project, it shows that high performers made far greater use of this source of technical information (Figure 1). As a matter of fact, high performers not only report a significantly greater frequency of consultation with organizational colleagues, they also spend significantly more time in their discussions with colleagues.

In order to better understand the ways in which internal consultation can be used most effectively, it would be interesting to learn more about the kinds of people who are consulted, and what sorts of internal consultant make the most important contributions to performance. Looking first at the number of different people with whom project members consulted, it appears that high performers consult with a far greater number of people than do low performers. Furthermore, they rely on more people both within their own technical specialty and in other specialties (Figures 2a and 2b). The high performer is in closer touch than the low performer with developments in his own field. Through his wide range of contact within his specialty he is less likely to miss an important development which might have some impact on the problem to which he is assigned.

He also has wider contact with people in specialties other than his own. In fact, it is only the high performers who show any real contact outside of their specialty (Figure 2b). The low performers seldom ventured outside of their field. The diversity shown by the high performer is quite important. One proposed explanation of the process underlying creative thought holds that it involves the linking together of very remotely associated ideas in a useful context (Mednick, 1962). One way in which remote associations can occur is through the integration of two independent fields of activity. Very often the components for a creative innovation can lie separately unnoticed

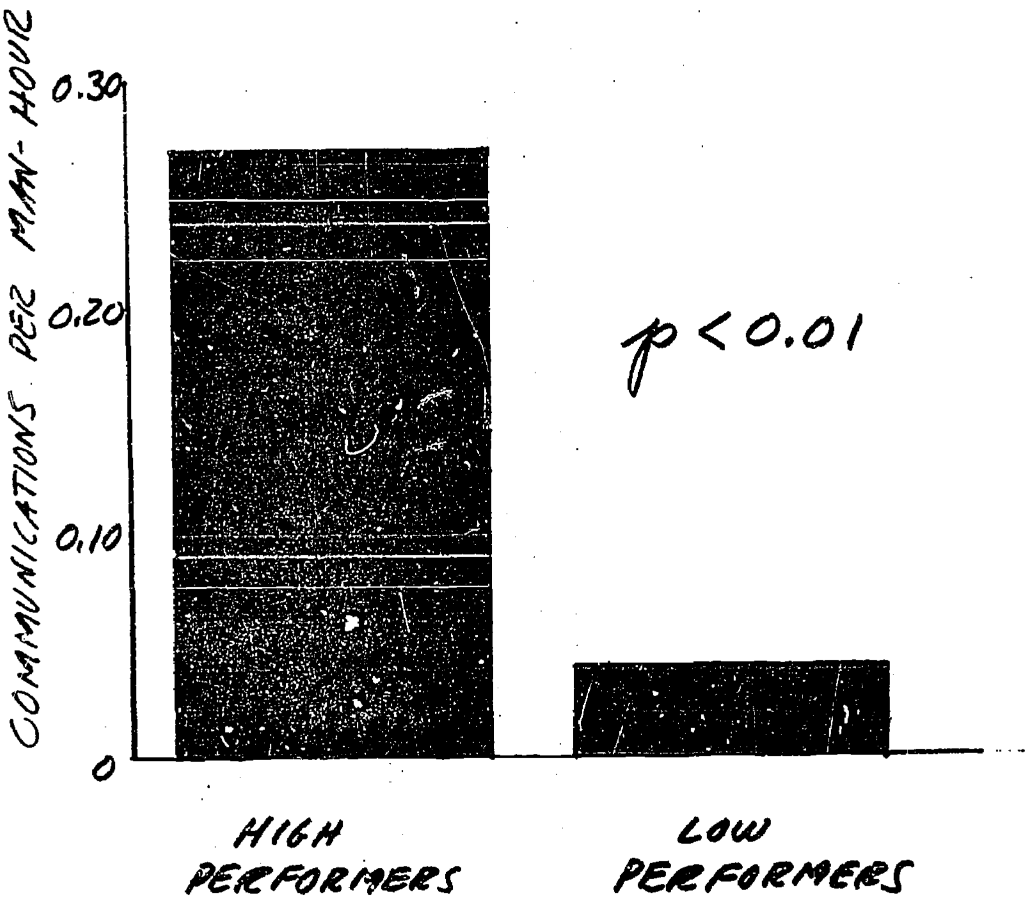


Figure 1. Extent of Communication Between R&D Project Members and Organizational Colleagues Not Assigned to the Project

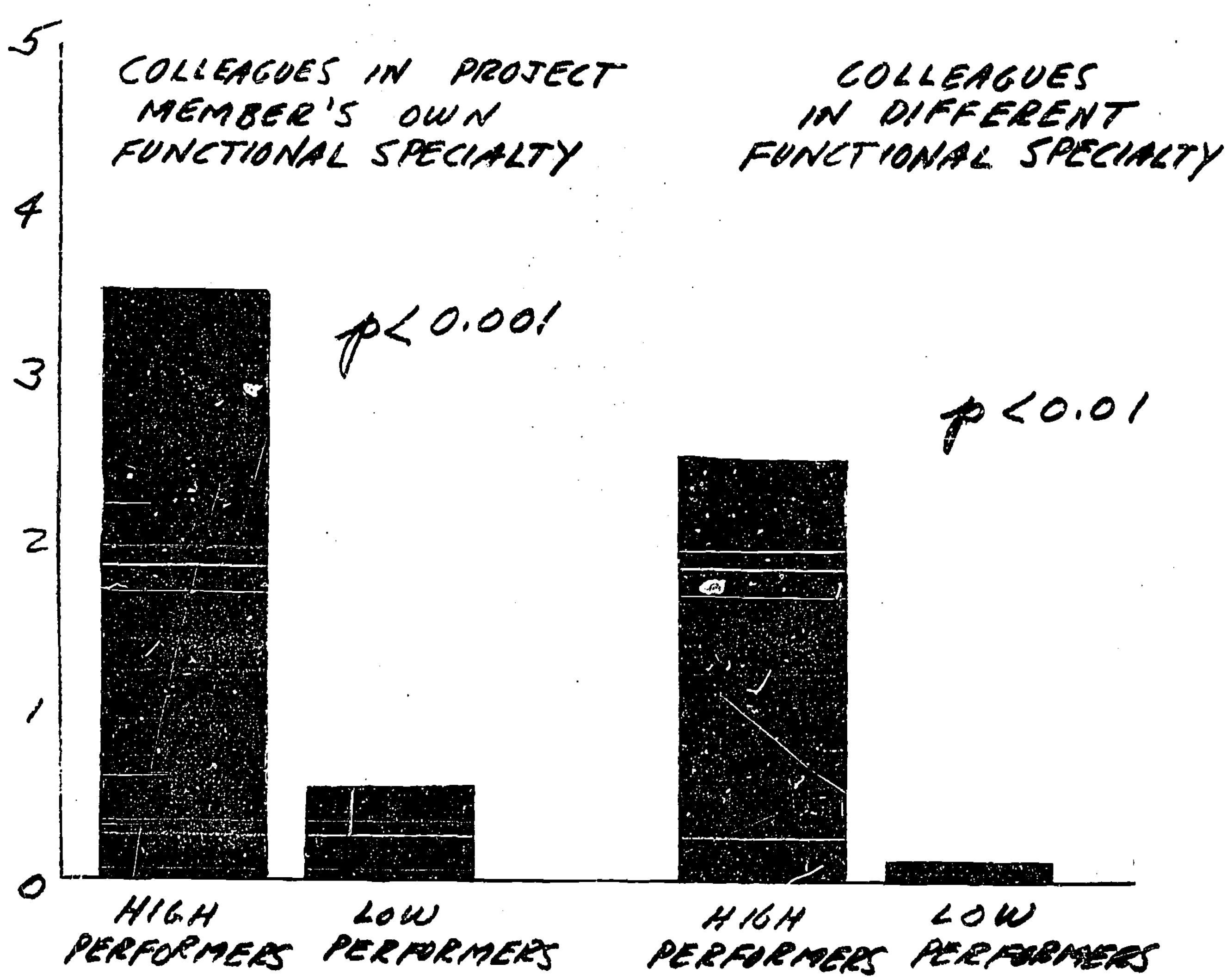


Figure 2. Number and Location of Organizational Colleagues with Whom Project Members Communicate

for long periods of time in two fields between which there is little interchange. It is only when some communication is established between the fields that an association between the components is enabled and the innovation can occur. This is why great scientific discoveries are often preceded by a movement from one discipline to another of the discoverer (see, for example, the case of Pasteur: Singer, 1959). Some components of the idea are brought from the old discipline, others are gathered in the new and the association of components from the two fields results in the new discovery or innovation. Pelz and Andrews (1966) found that changes in activity tended to rejuvenate scientists and engineers as they grew older, and offset any decline in their performance. They also found performance to be higher when a man combined several activities. These are both ways in which communication can be opened between two or more fields, increasing the probability of innovation. Perhaps closer to the present results, Pelz and Andrews also found that colleague contact both within the immediate work group and with other groups in the organization were positively related to a man's performance. The variety of contacts and their frequency each contributed independently to performance. Very similar results were obtained in the study by Allen and his colleagues, where both the frequency of discussions and the number of colleagues with whom the discussions were held were related, independently, to performance.

Pelz and Andrews are, in their analysis, able to go a step further and address the question of causality. One cannot of course determine from data such as those presented here whether communication causes high performance or whether high performers merely communicate more. Pelz and Andrews, in their study, obtained data on which of the two parties initiated the contact. They then assumed that a man's high performance would be more likely to attract contact from others than to induce him to initiate contacts himself. They then looked only at contacts initiated by the information user and found that the relation with performance remained strong. They conclude:

> " ... large amounts of colleague contact tended to go with high performance even when one looked only at scientists who themselves were the primary initiators of the contacts. Under these conditions it was difficult to believe that the contacts were primary the <u>result</u> of previous high performance. Thus the hypothesis that contacts with colleagues stimulated performance seemed to be supported." (p. 47)

<u>Support from Outside the Project: A Paradox</u>

The preceding paragraphs have gathered together a very substantial body of evidence for the relation between consultation with organizational colleagues and project performance. Given the benefits to be derived from internal consultation, one would expect project members to rely heavily upon their technical staff for information. In fact, this is not the case. During the course of most research and development projects, very little use is made of technical staff support. As a matter of fact, during the 19 projects studied by Allen (1966), project members actually obtained more of their ideas from outside of their firms than from their own technical staff. This is especially surprising in view of the poor performance shown by sources outside of the firm. In fact, when individuals inside and outside of the firm are compared as sources of ideas, there is an inverse relation between frequency of use and performance (Table I). Those information sources that reward the user by contributing more to his performance are used less than those that do not. Such a situation would seem to conflict with the principles of psychological learning theory. One might expect a person to return more frequently to those channels that reward him most consistently. The data show just the opposite to be true. The paradox can, however, be resolved with the introduction of an additional

Table I

Relation Between Frequency of Use and Performance of Information Sources

| | performance | frequency of use |
|---|---|---|
| sources outside of the firm | lo | hi |
| sources within the firm | hi | lo |

parameter. It can be safely predicted that an individual will repeat a behavior that is rewarded more frequently than one that is unrewarded, only if the cost to him of the rewarded behavior is less than or equal to the cost of the unrewarded behavior. In other words, both cost and benefit may be taken into consideration when deciding upon a source of information.

Gerstberger and Allen (1968) actually studied this decision process in some detail. They found no relation at all between the engineers' perception of the benefits to be gained from an information channel and the extent to which the channel was used. However, a very strong relation existed between extent of use and the engineers' perception of the amount of effort that it took to use the channel. Cost in that case was the overriding determinant of the decision. Working back from this finding, one might speculate that the failure to consult with organizational colleagues is attributable to a high cost associated with such consultation. In fact, there is evidence to indicate that the organizational colleague is a high cost source of information for research and development project teams (Allen, et.al., 1968 ). It can, for example, be very costly for a project member to admit to a colleague that he needs his help. That is not easy for anyone to do. The situation is most difficult in the case of the organizational colleague, because the information-seeker must live with him afterward. This is further compounded by the element of competition that exists among organizational colleagues. In addition, on the consultant's side of the transaction, there is discouragement from the fact that the organizational reward systems normally do not recognize indirect contributions. Most organizations recognize only a person's direct efforts and are insensitive to the indirect assistance he may be providing to others. The subject of organizational reward systems is a very involved one, and could not possibly be given sufficient attention in a brief paper of the present sort. Suffice it to say that management might benefit from a consideration of the scoring systems used in basketball or ice hockey. In those sports, the man who passes to a teammate, who subsequently scores, receives at least partial credit for the goal, in what is known in the scoring columns as an "assist". Organizations would do well to emulate this practice and to record and reward "assists" as well as goals.

## Communication Networks

Following considering both the costs and benefits to the project of consultation within the organization, two questions remain. These two questions deal with the determinants of, in one case, benefits, and in the other, costs. Where do the internal consultants obtain their information? And what can be done to reduce the costs of internal consulting?

An answer to the first of the two questions is provided in a study by Allen and Cohen (1969). Allen and Cohen found that the people who were chosen most frequently as internal consultants differed from others in the organization in two respects. They maintained broader contact on an informal basis with technical colleagues outside of the organization, and they read far more of the professional engineering and scientific journals than did anyone else in the organization. These "technological gatekeepers", as they have been called, accomplish the extremely important mission of keeping the organization in contact with activities in the outside world. If then, the goal is to improve the degree to which the organization maintains this contact, to improve the process through which new technology is imported, it becomes important to understand more about the technological gatekeeper and how his services can be best utilized.

Networks of Gatekeepers

Using the techniques of the earlier (Allen and Cohen, 1969) study, the structure of the communication network in the research and advanced technology division of a large aerospace firm was measured. The laboratory under study was organized on a functional basis around five engineering specialties and three scientific disciplines.

The gatekeepers in each specialist department were identified, as well as the structure of the communication network in that department. Because of the complexity of the networks in such a large organization (Figure 3), an attempt was made to simplify them through graph-theoretic reduction.

A communication network (or portions thereof) can be characterized according to the degree of interconnectedness that exists among its nodes. There are several degrees of interconnectedness or "connectivity" that can exist in a network (Flament, 1963). In the present analysis, only that degree

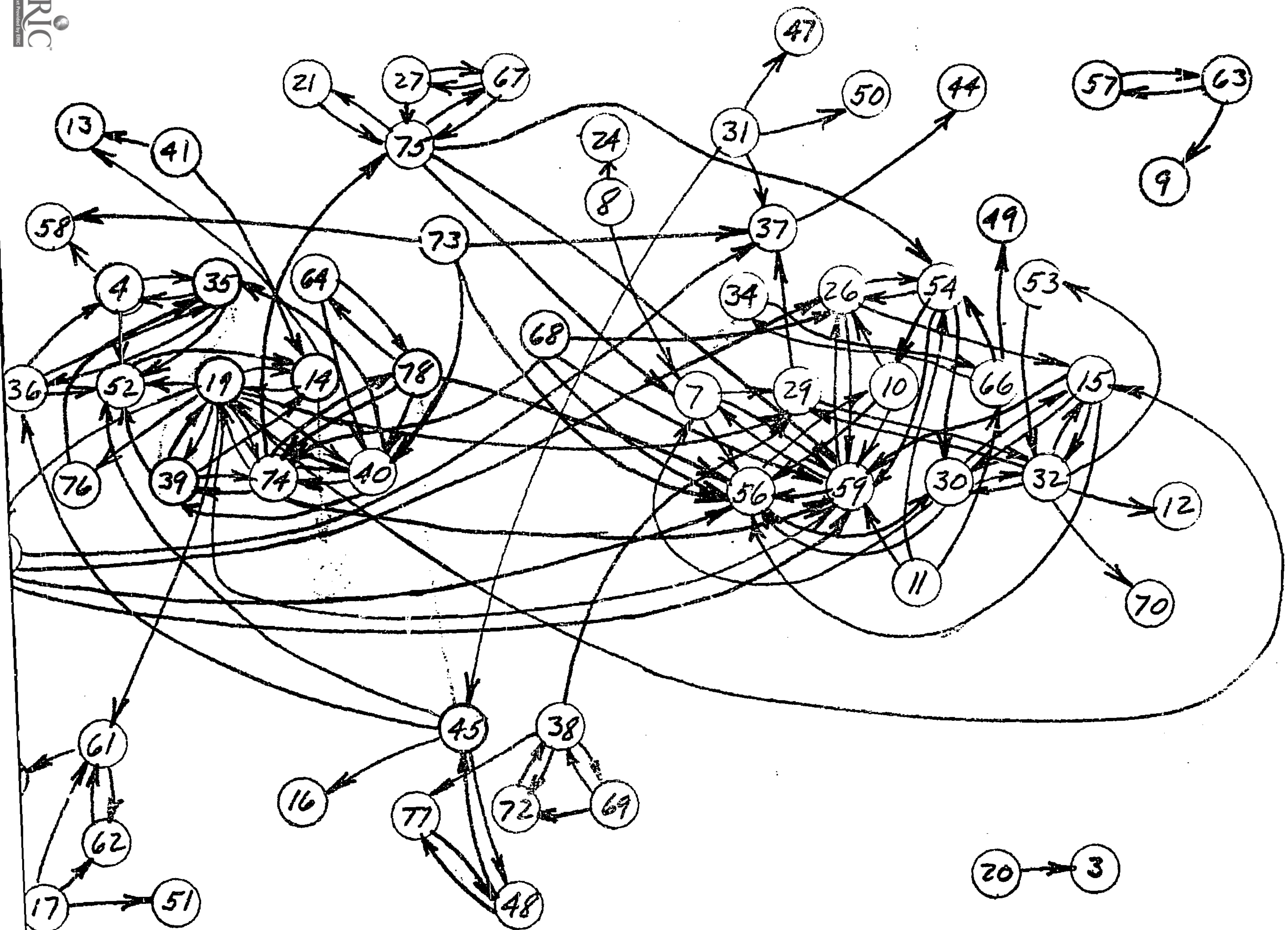


Figure 3. Typical Communication Network of a Functional Department in a Large R&D Laboratory

of connectivity which Flament has called "strong" will be considered. A strongly connected component, or strong component in a network is one in which all nodes are mutually reachable. In a communication network, a potential exists for the transmission of information between any two members of a strong component (Flament, 1963; Harary et.al., 1965). For this reason, the laboratory's communication network was reduced into its strong components and their membership was examined.

When the departmental networks of the organization are reduced in this manner, two things become apparent. First of all, the formation of strong components is not aligned with formal organizational groupings, and second, while there were in each functional department anywhere from one to six non-trivial strong components,[1] nearly all of the gatekeepers can be found together as members of the same strong component. (See, for an example, Figure 4.) On the average, 64 percent of all gatekeepers can be found in eight strong components, one for each of the five technological and three scientific specialties. In each technical specialty, there is one strongly connected network in which most of the gatekeepers are members. The gatekeepers, therefore, maintain close communication among themselves, thus increasing substantially their effectiveness in coupling the organization to the outside world.

In fact, if one were to sit down and attempt to design an optimal system for bringing in new technical information and disseminating it within the organization, it would be difficult to produce a better one than that which exists.

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[1]Median for eight departments, of approximately 50 professionals each, is strong components.

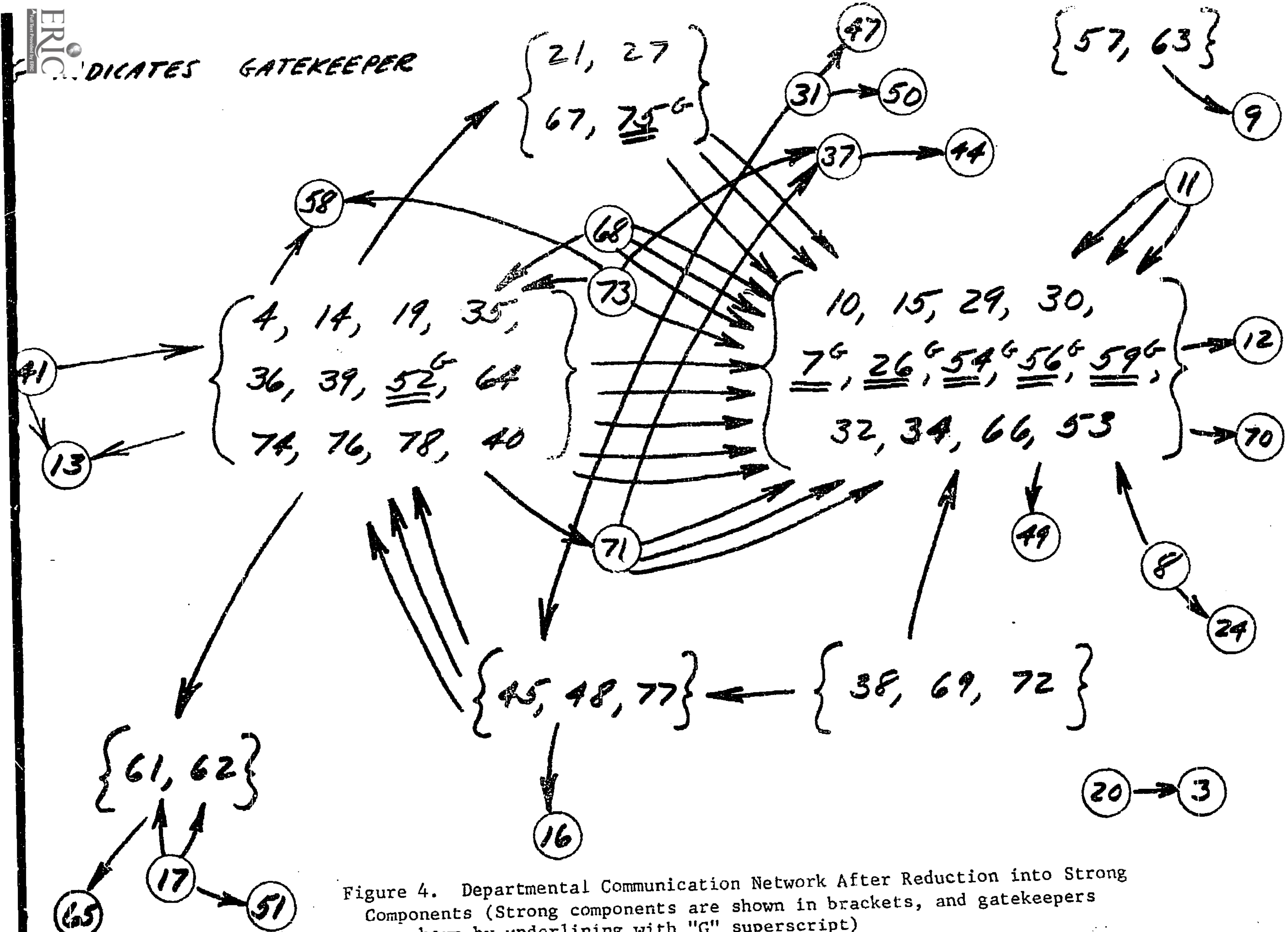

Figure 4. Departmental Communication Network After Reduction into Strong Components (Strong components are shown in brackets, and gatekeepers are shown by underlining with "G" superscript)

New information is brought into the organization through the gatekeeper. It can then be communicated quite readily to other gatekeepers through the gatekeeper network and disseminated outward from one or more points to other members of the organization (Figure 5). Perhaps the most interesting aspect of this functioning of the organizational communication network is that it has developed spontaneously, with no managerial intervention. In fact, there was scarcely a suspicion on the part of management that the network operated in this way.

The Influence of Non-Organizational Factors on the Structure of Communication Networks

An organization's formal structure (that which generally appears on an organizational chart) is, as one would expect, a very important determinant of communication patterns. It is not the sole determinant, however. In addition to formal organizational structure, there are available to management at least two other factors that can be used to promote (or discourage) communication. The first of these operates through the extension of informal friendship-type relations within the organization. Allen and Cohen (1969) have shown how informal relations influence the structure of communication networks, and Allen, et.al. (1968) explore in detail how this influence comes about. Simply stated, people are more willing to ask questions of others whom they know, than of strangers. The key lies in the expected damage sustained by the ego if one's question is met with a critical response. To be told that you have asked a dumb or foolish question is the ultimate in rebuffs. Few people are willing to entertain such a risk. Now, out of all of the people in the world, there are hopefully only a small percentage who would meet even a truly stupid question with such a retort. Even given that this percentage is very small, however, many people will follow the strategy of minimum regret and assume

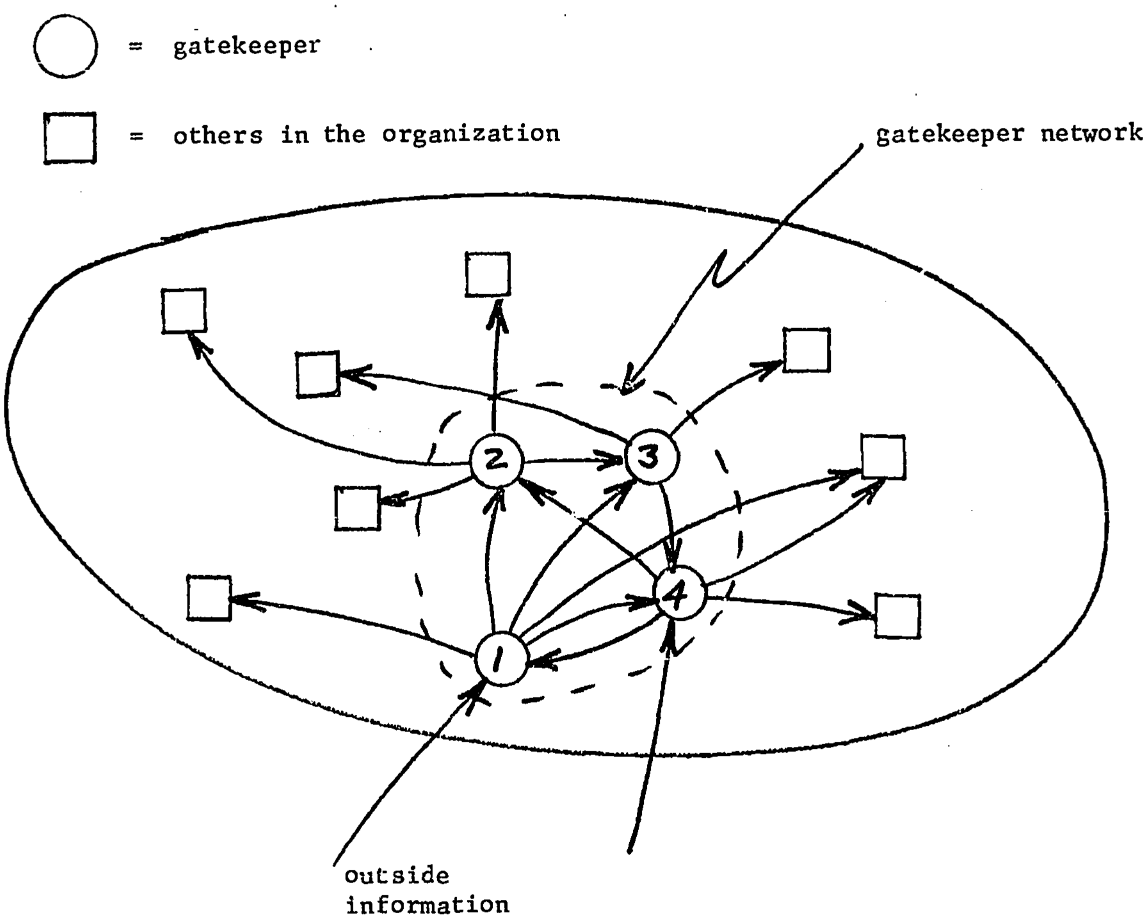


Figure 5. The Functioning of the Gatekeeper Network

New information is brough into the organization by 1. It can be transmitted to 2,3, & 4 via the gatekeeper network. It reaches its eventual users (squares) through their contacts with gatekeepers.

that everyone belongs to this set unless proven otherwise. This results in a situation in which, of all people who are known, only a small percentage are unapproachable, but all unknowns are unapproachable. To increase the proportion of people in the organization, who can be approached for information, management woul. be well advised to increase the number of acquantantanceships among its technical personnel. This it can do very easily. People will not become acquainted until they first meet. There are, however, a number of ways through which technical people can come to meet one another. Interdepartmental projects are one such device. People who come to know one another through service on projects or other inter-functional teams retain their effectiveness as channels between departments for some time even after the project or team had been disbanded. Inter-departmental teams of the type described by Galbraith in his introduction, provide an indirect benefit, through the persistence of the relations that they establish, over and above their direct contributions to coordination. The same thing can be said for transfers within the organization. For a period of time following a transfer, the transferred individual will provide a communication path back to his old organization. His influence extends far beyond this direct link, though. Probably the most important contribution of the transferred person lies in his ability to make referrals. The number of communication paths that potentially become available when a man is transferred is the product of the number of acquaintanceships which he develops in the two parts of the organization. For some people this can be a very large number. So with only a very few transfers, a large number of communication paths can be created and coordination thereby improved.

Of course, the effect diminishes with time, since both people and activities will change in the old group, and the transferred person will gradually lose touch. Kanno (1967) has shown that following a transfer between divisions of a large chemical firm, the transferred persons provided an effective communication link back to their old divisions for one to one-and-a-half years. The duration over which communications remain effective following a transfer is determined by many factors, principal among these are the rate of change of activities and turnover of personnel in the old organization. If projects are of short duration, with many new ones constantly being initiated and the turnover of personnel is high, one would expect that the effect of a transfer in promoting communication would be short-lived. Where the activity is more stable and turnover low, the transfer can be effective over a longer period of time. With estimates of these parameters and of the number of people (and their work) with whom the average transfer is acquainted, a systematic program of intra-organizational transfer can be developed. Such a program would contribute directly to communication, coordination and empathy among the sub-elements of the organization.

In addition to formal organizational and information relations there is a third very important factor that can be used to influence the structure of organizational communication networks. It shouldn't surprise anyone to hear that the pattern of communications in an organization can be influenced by the physical configuration of the facilities in which that organization is placed. What is surprising is the degree to which communications are sensitive to spatial arrangements.

The data on the effect of spatial separation to be presented now were obtained in three very different organizations. The first organization is a 48 man department in a medium-sized aerospace firm. The 48 people were all engineers and scientists, primarily in electrical and mechanical engineering and applied physics. The second organization that was studied is a 52 man section of a medical school laboratory. The third organization comprised 57 social psychologists, economists and applied mathematicians in a management school.

To determine the influence of physical separation on the probability of two people communicating, the distance between every possible pair of people was measured. Moving outward in five yard intervals from each person, a measurement was made of the proportion of people within each interval with whom the focal person communicated. The measurement of distance was the actual distance that the focal person would have to walk in order to reach another person's desk. All measurements were taken on a single floor.

The proportion of people with whom an individual communicates, or the "probability of communication" as it is labelled in the figure, decays with the square of distance outward from the focal person (Figure 6). The fact that the probability of communication decays with the distance separating people is not too surprising. Nor is the fact that it follows an inverse square law. What is surprising is the extreme sensitivity of probability to distance. The function, naturally, must become asymptotic beyond the minimum point of the parabola. The striking thing is that it reaches this asymptot within 25 yards. This was true in all three organizations. In fact, for the first two organizations, the curves fall so close together that the data are combined in Figure 6. The result, therefore, appears to be general and independent of the nature of the technical work being performed.

As though, by itself, physical separation were not serious enough, there appear to be circumstances which can exacerbate its effect. The amount of difficulty, by way of corners to be turned, indirect paths to be followed, etc., encountered in traversing a path intensifies the effect of separation on communication probability. One index of this difficulty, something which might be called a "nuisance factor" is the difference between the straight line and actual travel distances (Figure 7) separating two people. When communication probability is plotted as a function of the magnitude of the "nuisance factor" (Figure 7) the effect is quite startling. This effect holds true whether the nuisance factor is computed on an absolute basis or as a proportion of straight line separation distance.

The extreme sensitivity of communication to physical separation must be given careful consideration when positioning people within a building and when positioning buildings relative to one another. This is important both when designing new facilities and when locating people or groups in existing facilities.

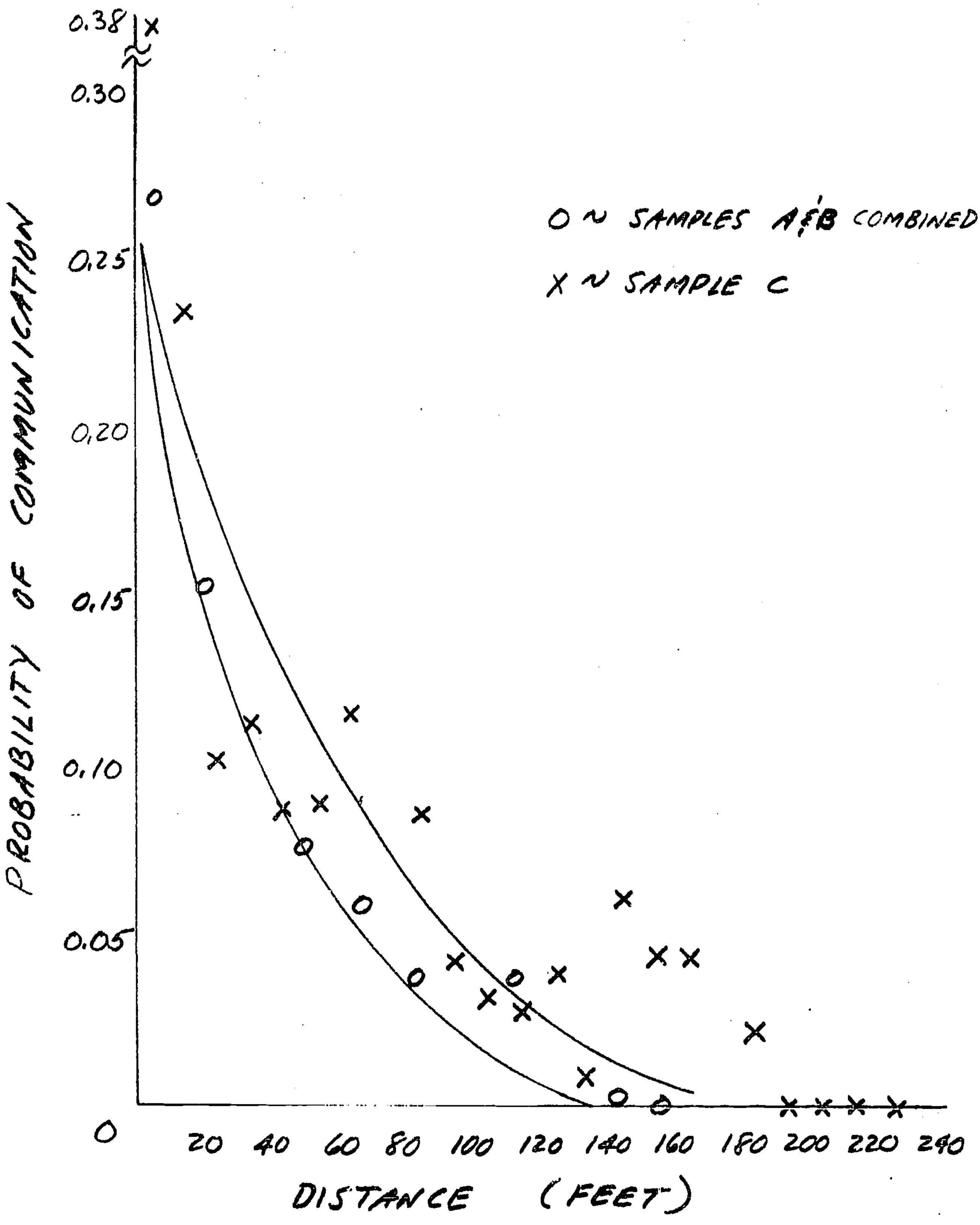


Figure 6. Probability of Communication as a Function of the Distance Separating Pairs of People

To encourage communication between project teams and the supporting technical staff, separation distances must be kept to a minimum. To locate a project in a separate facility is to essentially cut it off from support by the rest of the laboratory staff. There is a tradeoff that must be made in locating project members. Effective coordination of all elements of project activity may require that all or most of the team members be located together in a specially assigned place. On the other hand, to maintain the specialists assigned to the project abreast of developments in their technical fields demands that they be kept in contact with their specialist colleagues. This, in turn, favors locating them with their specialist groups. Later in this conference, Marquis (1969) will present results arguing for the latter alternative on very large projects. All of the projects in Marquis' sample were of fairly long duration, several years. This may well hold the key to the tradeoff. For long term projects, technical personnel should remain in the same location with their specialist colleagues. Assignment to a project of long duration can force a man to lose touch with his field unless steps are taken to enable his free interaction with colleagues in the field. The result is technical obsolescence and difficulty for both the man and the organization in dealing with future assignments. In the case of a brief project, the length of separation will be too short to have these results, and the balance swings in favor of locating all project members together. Long projects then demand functional organization, while short duration projects may be organized on a project basis with all team members located together. The interpretations of long and short will, naturally, vary from one field to another and are largely a function of the rate of technological advance in each field. In the more rapidly changing fields a man is more subject to obsolescence, if separated. In more stable fields, the obsolescence risk is less and project assignments can be made accordingly. Marquis (1969) shows how this operates in the extreme. Taking the physical technologies to represent the dynamic end of the spectrum and such administrative technologies as contract law and accounting to represent the more stable end, he finds performance to be higher for the former when functional organization is used and for the latter under project organization. For more dynamic technologies the length of time that a man can be separated from his field is quite short. For less rapidly growing technologies this time can be much longer.

Of course, functional organization has the undesirable consequence of making intra-project coordination difficult. A possible solution to this problem lies in overlaying a coordinating team across the functional departments in what has come to be known as a matrix organization. This is not always as easy to accomplish as it first sounds, but when it functions properly it can achieve the desired goals of the functional organization without the loss in project coordination. Matrix organization is a subject that has been analyzed in great detail elsewhere. (See, for example, the papers by Lorsch, 1969, and Jacinski, 1969.)

All three organizational schemes, bur especially functional and matrix organization have the undesirable consequence of making communication between functional departments difficult. Transfers, where possible, and short duration inter-departmental projects assist in countering this problem. In addition, the overall configuration of the laboratory should be structured in such a way that inter-functional communication is eased. Where it is desirable to have communication between groups, they should be located near each other. There this is impossible they can be made to share certain facilities that will force interaction. The nature of the facility is secondary. It may be as humble as a coffee pot or men's room or as grandiose as a computer or an expensive instrument. What matters is that it brings people into contact who would otherwise not meet. It is quite easy, in any organization, to think of a large number of such facilities for promoting interaction. Where possible they should be located where they will promote the desired patterns of group interaction. In those cases in which it is not feasible to manipulate the position of the interaction facility, then desired patterns of interaction should be given serious consideration in allocating the use of the facility among groups and in positioning groups around it. In the latter situation it must be borne in mind that the extent to which a facility will be used is also an inverse function of distance. Frohman (1968), for example, found the principal determinant of use of a technical library in an industrial firm to be the distance separating users from it. Interaction facilities must be positioned in such a way that they promote interaction among groups that would not otherwise interact, while at the same time they are not so far removed from any of the groups that they lose their effectiveness.

## Summary and Conclusions

The importance to research and development projects of technical staff support cannot be overstressed. Seldom, if ever, is management able to satisfactorily predict and obtain all of the talents that will be needed in a project and incorporate them in the project team. The project must, therefore, obtain much of its required information from sources beyond its own membership.

Research shows very clearly that the best source for this support lies in the technical staff of the laboratory itself. Attempts to bring information to the project directly from outside of the organization usually have been ineffective. The process by which an organization imports and disseminates outside information is more complex than people normally assume. The best way to maintain the project team abreast of outside developments lies in understanding and making proper use of existing information systems. This involves the use of technological gatekeepers for project support. Outside information can then be delivered to the project quite effectively, albeit by an indirect route. Research evidence indicates quite strongly that the indirect approach is far more effective than any direct approach to coupling project members to outside sources, whether personal or written.

There are available a wide variety of techniques for improving communication and coordination between projects and their supporting staff. A number of formal organizational mechanisms have been described in detail during the course of the present symposium. In addition to these, use may also be made of the informal relationships that will develop when people come into contact with one another. A very effective means for increasing the level of acquaintanceships in an organization is the inter-group transfer. Physical location is also a very strong determinant of interaction patterns. People are more likely to communicate with those who are located nearest to them. Individuals and groups can therefore be positioned in ways that will either promote or inhibit communication. Architectural design thus becomes an important determinant of the structure that an organization's communication network will assume. Shared facilities or equipment can also be used to promote interaction between groups.

All of these factors must be taken into account and properly arranged in order to effectively couple the research and development project to its supporting information system.

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