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Research Laboratory Architecture and
the Structuring of Communications

by

Thomas J. Allen and Alan R. Fusfeld

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We would like to begin this paper with two simple observations, with which most readers will probably agree:

1. Communication is an essential part of the research and development process. The performance of an R&D organization is highly dependent upon good communication among the staff.
2. The interaction patterns that develop among the inhabitants of a building or set of buildings, are very strongly affected by the shape and relative location of the buildings.

These are two seemingly obvious and innocent enough statements, but they have very strong implications for the physical design of research laboratories. If communication is such an important determinant of R&D performance, (see, for example, Allen, 1970) and if it, in turn is strongly influenced by physical layout, then it follows directly that communication among the inhabitants should be an important criterion in the physical design of a research laboratory. In spite of the self-evident nature of this conclusion, one does not have to visit very many R&D establishments before concluding that it is observed in the breach if at all. It would certainly require an extensive search to find even a few instances in which the architectural design involved a conscious attempt to promote intramural communication.

There are two reasons for this apparent neglect. First of all, while most research managers would concur in the importance of communication, it is only recently that the degree of that importance has been convincingly demonstrated and underscored by empirical research. Most architects have therefore been unaware of the true importance of communication to the occupants of research laboratories.

In addition to this, there has been very little research exploring the nature and sensitivity of the relationship between physical layout and communication within buildings, and none of this until the present time has dealt with research laboratories as a specific case.

The present paper will attempt to remedy this latter situation, with data from a number of existing research laboratories. First, however, let use briefly review the evidence for the importance of communication in research and development organization.

Organizational Communication and Performance

A large number of studies have now shown organizational communication to have a very strong influence on R&D performance. Allen (1964), for example, found that those proposal teams that consulted more with colleagues within their own organization produced higher quality proposals. In two subsequent studies, Allen, and his colleagues, showed that for matched pairs of identical projects, engineers who obtained ideas from organizational colleagues (1966), or who consulted more within their organization, during the project (1970), produced better technical solutions. Pelz and Andrews (1966) found that colleague contacts within the immediate work group and with other groups in the organization were positively related to a scientist's performance, and that both variety and frequency of contacts contributed independently to performance. Baker, et. al, (1967) found that "idea generating groups" in a large electronics firm obtained their best new product ideas from within their own organization, despite an extensive search outside of the organization. Hagstrom, (1965) in a study of academic researchers in mathematics and in physical and biological scientists found a positive correlation between performance and intra-departmental communication. Finally, Shilling and Bernard (1964) found in

64 biological laboratories, that the degree to which internal communication was stimulated was significantly correlated with seven out of eight measures of laboratory performance.

The evidence is quite strong, and demonstrated clearly the importance of intra-organizational communication for the scientists or engineer. The managerial question is one of determining just what can be done to improve communication. There are of course many possibilities, the present paper will consider just one of these, building architecture.

Propinquity and Behavior

There is a long history relating human interaction to relative location. Laboratory experiments by Leavitt (1951), Steinzor (1950), Sommer (1969), Strodtbeck and Hook (1961), and Hare and Bales (1963) have shown that not only does the explicity communication network affect the direction frequency of interaction in small groups but also that inherent in the seating arrangements is an implicit network which influences the interaction patterns of the gorup. For example, Steinzor found that within a circular seating arrangement group members interacted more with individuals opposite them than with those adjacent to them. Sommer (1969) was able to significantly increase the incidence and duration of conversation among patients in a nursing home by re-arranging the location of chairs in a day-room. Sommer goes on to document in numerous settings the interaction between spatial factors and human interaction.

A number of field experiments have also revealed the importance of propinquity in promoting interaction. Festinger, Schachter, and Back (1950) examined the relationship between physical distance and sociometric choice in a housing project and found that the most highly chosen individuals lived closest to their choosers, and as distance from the selector was increased the frequency of choice decreased continuously.

In an organizational context, Gullahorn (1952) studied the interaction pattern of twelve women in an office of a large eastern corporation. Specifically it was found that distance was the most important factor in determining interaction, and when physical proximity did not account for interaction, friendship seemed to be the controlling factor.

Even the choice of a marriage partner has been shown to be significantly influenced by physical proximity (Abrams, 1943; Kennedy, 1943). Although it would seem that the results, in part, could be attributed to ethnic concentrations in neighborhoods, in 1940 35 percent of the marriages in New Haven occurred between individuals who lived within five blocks of each other.

Propinquity was described by Maisonneuve (1952) in his study of a large educational institution as the variable which significantly influenced the formation of friendships among students in a classroom. He concluded that "very often people did not get closer to each other because they had a liking for each other, but they are inclined to have a liking for each other because they are close to each other".

It would appear, then, that the physical layout may be a strong determinant of communication choices within an organization, and it is to this possibility that we will now turn our consideration.

RESEARCH METHOD

In seven R&D laboratories, communication patterns were measured by either asking individual engineers and scientists to indicate which of their organizational colleagues they communicated with ("about technical or scientific matters") at a frequency of once a week or more, or by sampling communication by means of a questionnaire administered weekly on randomly chosen days. The questionnaire listed the names of all professionals in the organization and participants were asked at the end of a day, to indicate the number of times they had communicated about technical and scientific matters, over the course of the day, with each colleague listed. Communications were sampled, in this way, for periods of from three to six months. A computation was then made to determine which pairs of individuals maintained regular communication at an average frequency of at least once per week.

The laboratories in size from 48 to 170 professions, and included two laboratories in the aerospace industry; two in universities; one each in the chemical and computer industries; and one government agricultural research laboratory. Data were obtained from a total of 512 respondents in the seven organizations.

Distance between respondents was measured by means of facilities diagrams supplied by the organizations, and in the case of extended distances, by maps. In the first six cases, distance was measured from desk to desk; in the seventh organization distance was measured from building to building. In all cases, each engineer or scientist was taken, in turn, as a focal person and the actual walking distance from his desk to that of every other engineer or scientist in the organization was recoreded. These were then aggregated in intervals of about 10 feet or three meters. In each three meter interval (Figure 1) the ratio was computed of the number of individuals with whom the focal person communicates to the total

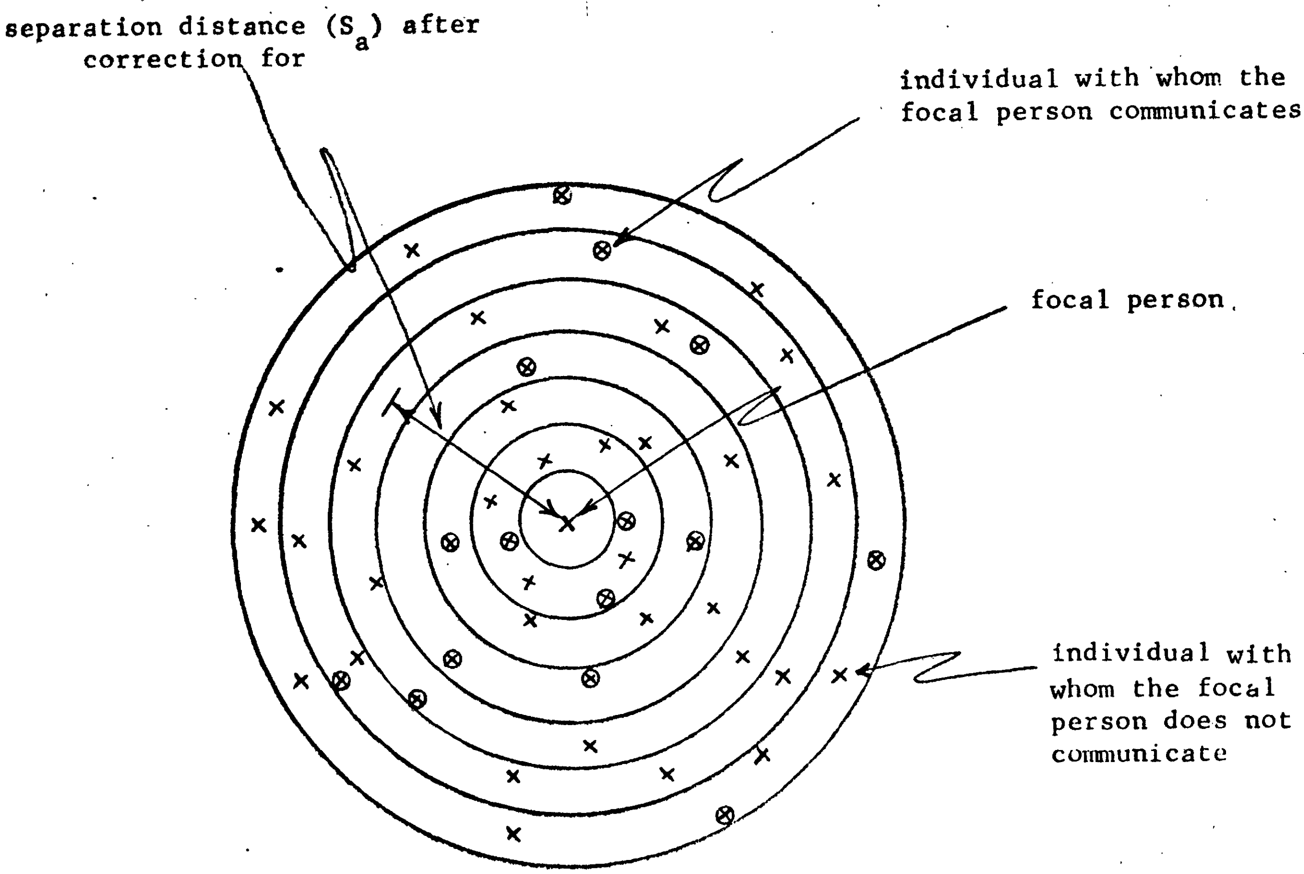

Figure 1. Method for Determining the Effect of Separation Distance on Communication (frequency of communication held constant)

number of people available. Such a ratio can be computed for any frequency, of communication, e.g., one or more times per month, one or more times per day, etc; the present analysis is based upon an average frequency of one or more communications per week.

RESULTS

Communication as a Function of Distance

The ratio represents, on the average, the proportion of available people with whom an individual will communicate at a given distance and frequency. The aggregate ratios, for all respondents are shown in Figure 2 as the probability that two people will communicate about scientific or technical subject matter.

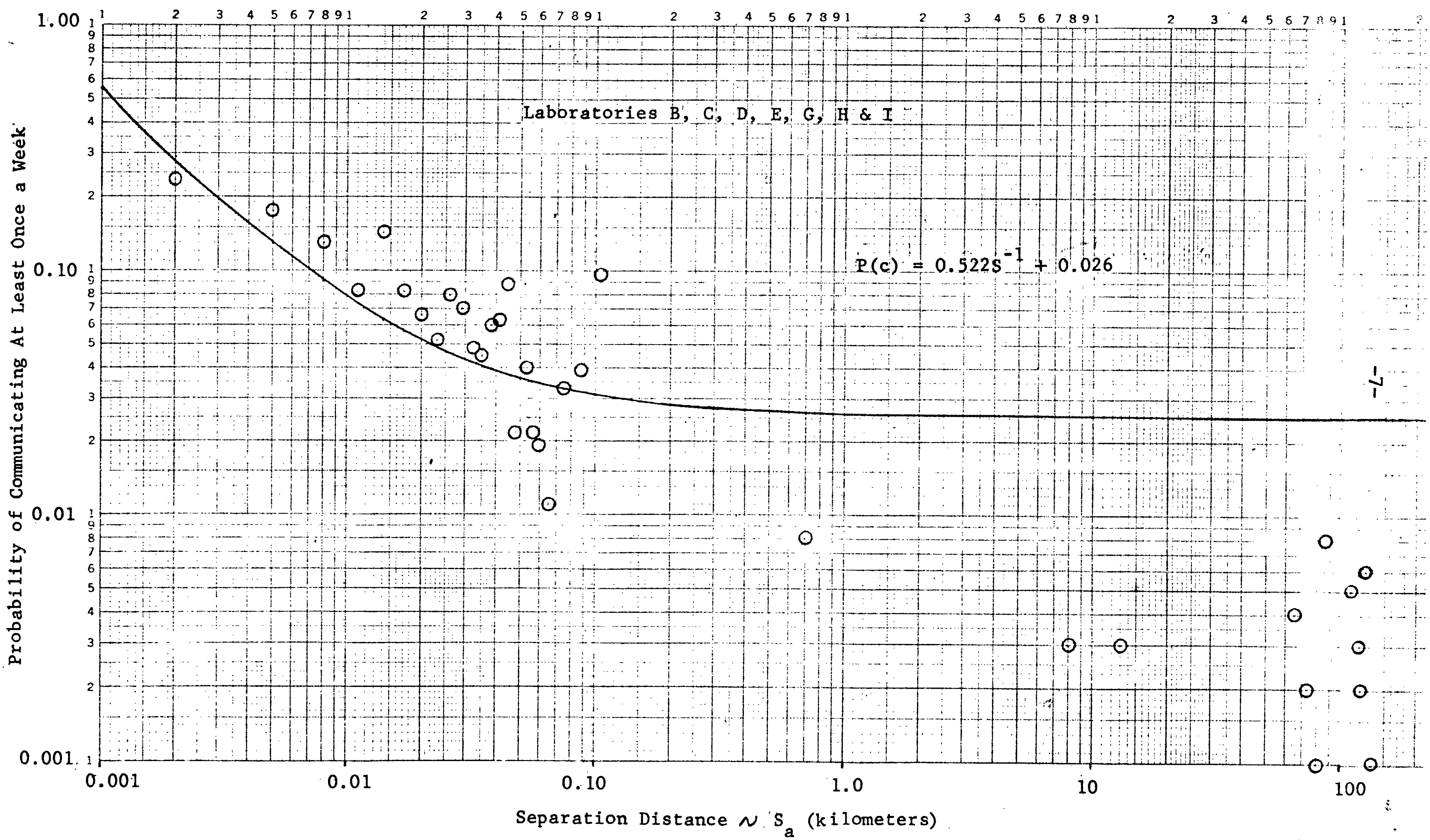

Figure 2. The Probability That Two People Will Communicate as a Function of the Distance Separating Them (100 meters to 255 kilometers)

The scales of Figure 2 are in logarithmic form in order to accomodate a range of separation distance, from 2 meters to 255 kilometers. Figure 3 is a better illustration of the effect of distance on communication probability within the first 100 meters. Here it can be seen that the regression curve is a hyperbola with a correlation coefficient, r = 0.84.

In considering Figure 3, the general shape of the curve is probably not terribly surprising to any one. One would expect probability of communication to decrease with distance. One might even expect it to decay at a more than linear rate. It is the actual rate of decay, in Figure 3, that is surprising. Probability of weekly communication reaches a low asymptotic level within the first 25 or 30 meters. It is this extraordinary rate of decay more than the general shpae of the curve that is so startling. For weekly contact, it is only within the first 30 meters that separation has any real effect on the probability of communication!

If communication frequency is increased or decreased, the curve of Figure 3 shifts up or down accordingly, but the shape remains essentially the same. The frequency of once a week or more was chosen arbitrarily to represent quite regular and consistent communication.

Organizational Bonds

One possible objection to Figure 3 would be that any individual, for organizational reasons, is more likely to communicate with those nearest to him. Space in most organizations is allocated on a group basis, with people of similar background, or people working on the same or similar tasks located near each other. Since an individual is more likely to communicate with those with whom he shares a common task or background, the decay in communication with distance is then simply an artifact of organizational location. TO test this possibility, the data from one

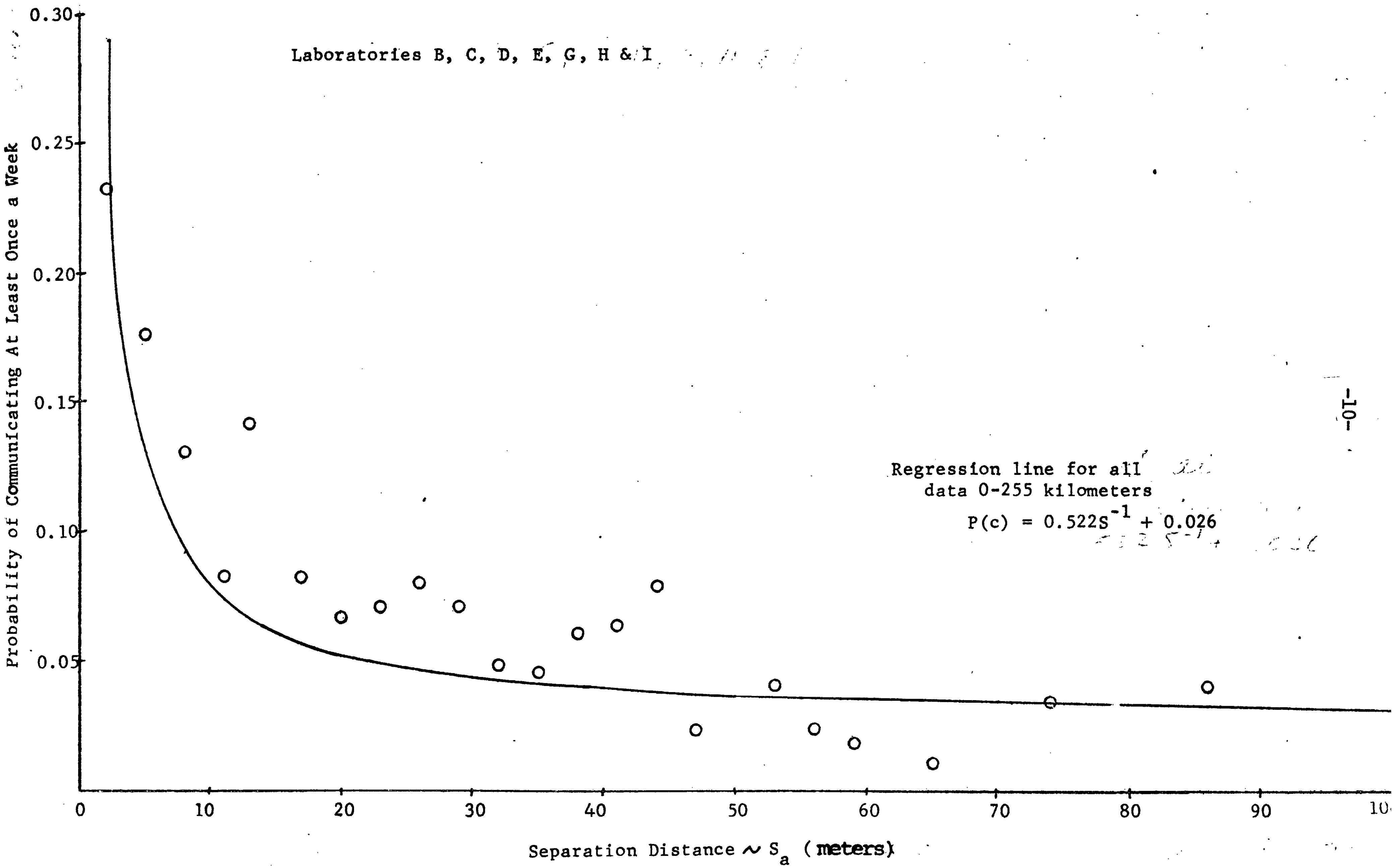

Figure 3. The Probability That Two People Will Communicate as a Function of the Distance Separating Them (0-100 meters)

of the seven laboratories were separated into two groups. Separate curves were then plotted for those pairs who shared an organizational group affiliation, and those who do not (Figure 4). The resulting curve for intra-groups communication lies above that for inter-group communication, as expected, but the general shape of the two curves is about the same as before. Common group affiliation merely shifts the relationship onto a higher curve, but the distance effect still operates in the same manner. The probability that an individual will travel a given distance to talk with someone in his group is slightly higher than the probability for someone in a different group. Both probabilities decay along a hyperbola and soon reach a low asymptotic level. The presence of the group bond merely introduces a relatively constant positive bias.

Office Arrangements

These results have a very clear message for those who are responsible for the design of research laboratories. The classical approach of arraying offices in a linear fashion along a hallway (figure 5) maximizes the separation distance between occupants of the offices, and is hardly the best way to promote communication.

To minimize separation, one should approach a circular or square configuration. Of course, in the case of large organizations it si impossible to have everyone within a 30 meter radius. This would be true, even if the building were circular. On the other hand, one need not go to the extremes seen in many research organizations, which look like an alphabet soup with building in the shape of H's, N's, Z's and even W's. Usually such buildings result from a desire to give everyone an outside exposure. While it si very nice to be able to see outside of one's building and determine whether it is raining, or snowing or whatever, there are

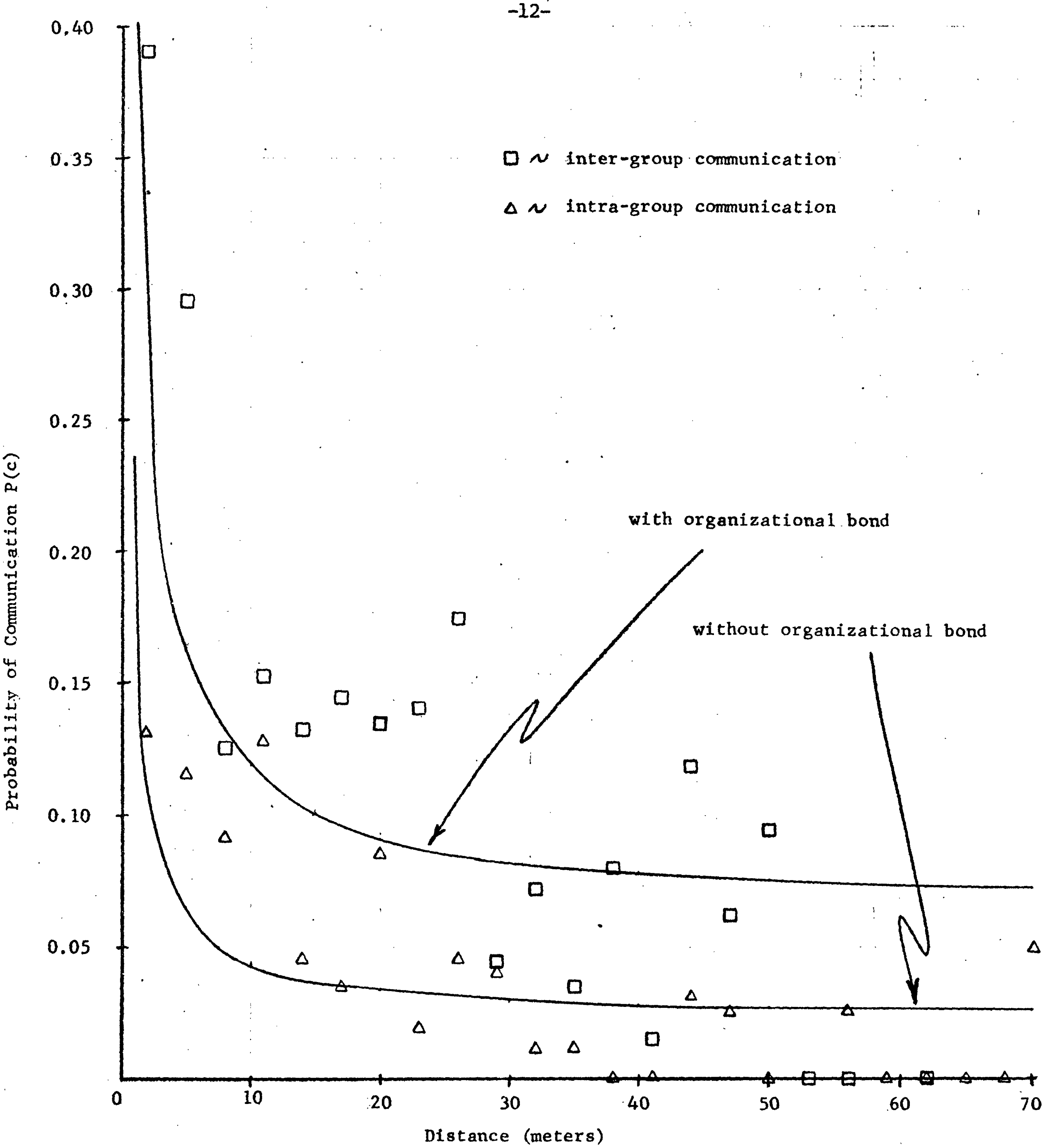

Figure 4. Probability of Communication As a Function of Distance -- Controlling for Organizational Structure

other ways to permit this without causing the extreme isolation that the elongated shape produces. One possibility is to move hallways to the exterior wall and provide windows along the hallways. Common areas, such as libraries, meeting rooms or coffee lounges can be given the windows. There are many ways

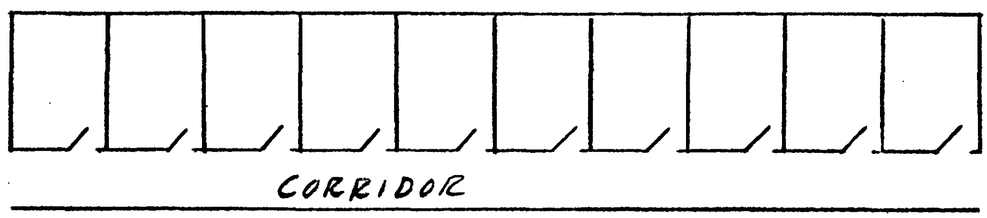

Figure 1-5. The Classical or "Pigeon-Hole" Form of Office Layout

of giving everyone some access to an outside view, without arranging offices in such a way as to provide each one with such access. The less differentiation there is in the desirability of office locations, the greater the flexibility possible to making office assignments. One thing is certain, if the head of the organization wants to keep in close touch with what is going on in his organization, he must resist the temptation to locate his office in the corner with the best view. The center of the building is the place for him. This will minimize average separation between his office and the location of the groups reporting to him. Otherwise, he is going to be farther from some groups than others with a corresponding degradation in communication.

Vertical Separation

Up to this point, the vertical separation between floors in a building has not been treated explicitly. The data would indicate that the vertical separation has at least as sever an effect as horizontal separation on communication (Peters, 1969). THis effect depends upon many factors in addition to actual distance. The location of stairs or elevators, their accessibility (e.g. whether the stairs are protected by a fire door), and the amount of visual contact that they allow, all enter in. In most office buildings, the actual length of the stairs between two floors ranges between 9 and 15 meters, so it is reasonable, on the average to assume a one-story separation to be at least equivalent to that amount of horizontal separation. Elevators do not seem to change this situation. People are just about as reluctant to use an elevator, as to climb stairs, The difference between stairs and elevators becomes pronounced as the number of floors in a building increases. It can be assumed that while people's reluctance to travel on an elevator increases only slightly as the trip increases from one to 10 stories, the difference between climbing one story and climbing 10 on the stairs is considerable. As a matter of fact, people are probably much less than one-tenth as willing to climb 10 stories as one.

The data gathered thus far are incapable of either confirming or denying any of the above conjecture, but it nevertheless seems fairly clear that housing an organization in a tall building can lead to communication problems.

This does not mean that single story buildings are desireable in all cases. After all, land values must be taken into account, and even ignoring this, as floor area increases a point must be reached at which the average separation between offices in a single story building exceeds that in a multi-story building, of the same area.

An oversimplified example of this can be pursued by assuming a square building, with no interior walls or corridors, each occupant assigned a 10 m. by 10 m. square segment of the floor, and with a staircase located in the center of the building. Floor area can then be increased and mean separation distance between occupants computed for cases in which that area is distributed over one or more floors. The length of the staircase will be assumed to be 12 meters.

Under these assumptions, there appear clear break points at which mean separation distance will be decreased by adding floors to the building (Figure 6).

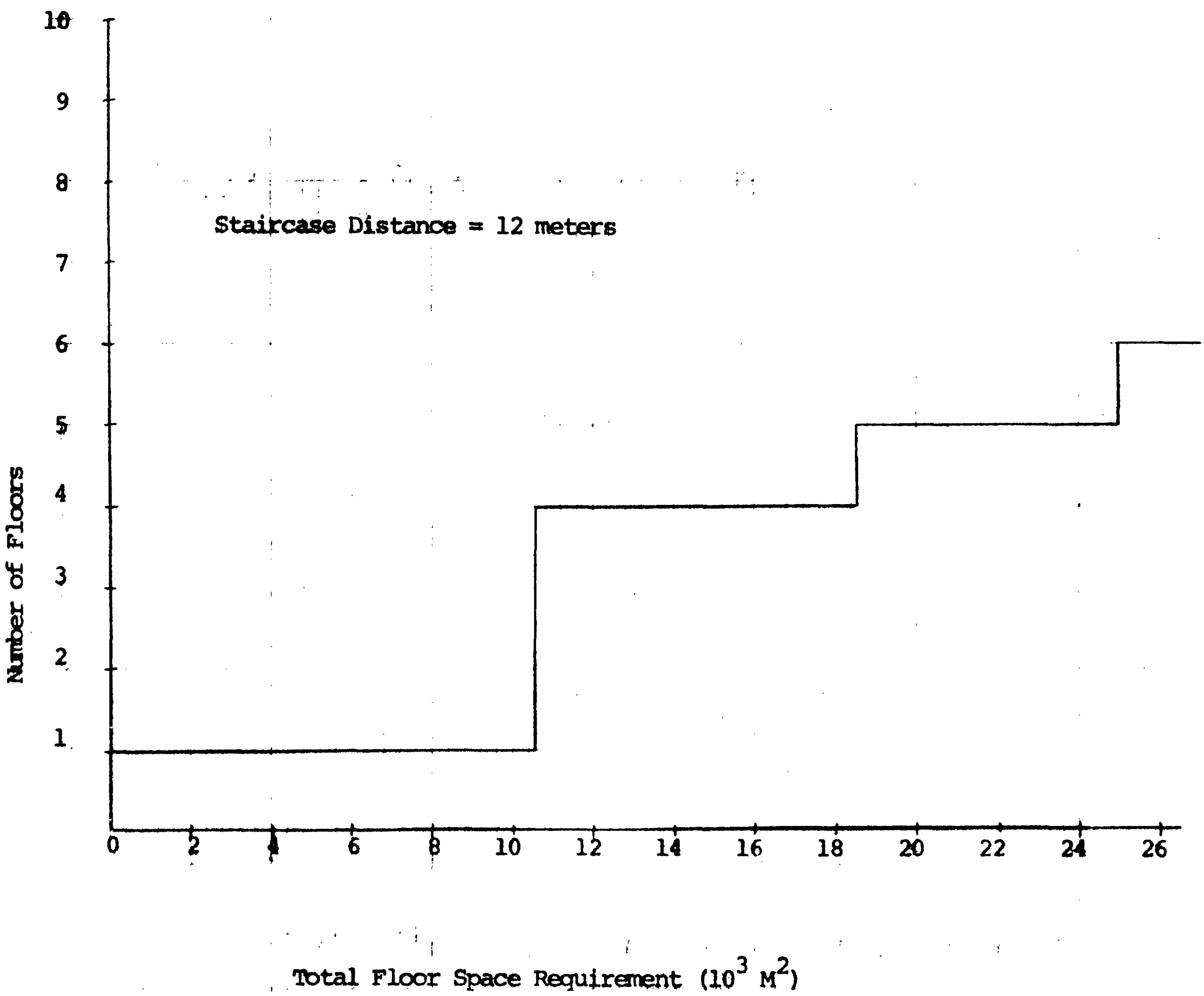

Figure 6. Number of Floors Required to Minimize Separation Distance Between Occupants in a Building (Square building, with staircase in center, [illegible] square meters per occupant and no internal walls).

The first three such points occur at 9,800, 17,000 and 23,000 meters, respectively. Moreover, the break at 9,800 square meters involves a shift from one floor to four floors! Given the initial assumptions, of the problems, one would never want to build a two or three story R&D laboratory. The reason underlying this lies in the fact that in the region between 9,800 and 17,000 square meters, the mean distance between people located on <u>different</u> floors is always greater in two or three-story building than in a four story building with the same floor space.[1]

Of course, the initial assumptions in the foregoing problem are grossly oversimplified. For example, the effect of a staircase is assumed to be the same as 12 meters of horizontal separation. This accords with the data reasonably well for a single flight of stairs, but it is probably not safe to assume that two flights are equivalent to 24 meters, three flights to 36 meters, and so on. The relationship is probably non linear, with the equivalen in horizontal distance increasing, as the number of floors increases.

To see what happens when one tries to account for this, the initial assumptions might be modified in the following way. Assume again that the separation between the first and second floors is 12 meters, but that the distance between the first and third floors is 2.25 times that distance, the three flights are equivalen to 3.75 times one flight, four flights equivalent to 5.50 flights, and so on. THe results are shown in Figure 7. The first three break points now occur at 9,000, 18,000 and 36,000 meters. Now the first shift is from one to three floors, but one would still never want a two-story building.

Once a laboratory building has more than two floors, one would probably want to introduce elevators. Although people appear to be just as reluctant to travel

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[1]See Fusfeld & Allen (1974) for a more complete explanation of this phenomenon.

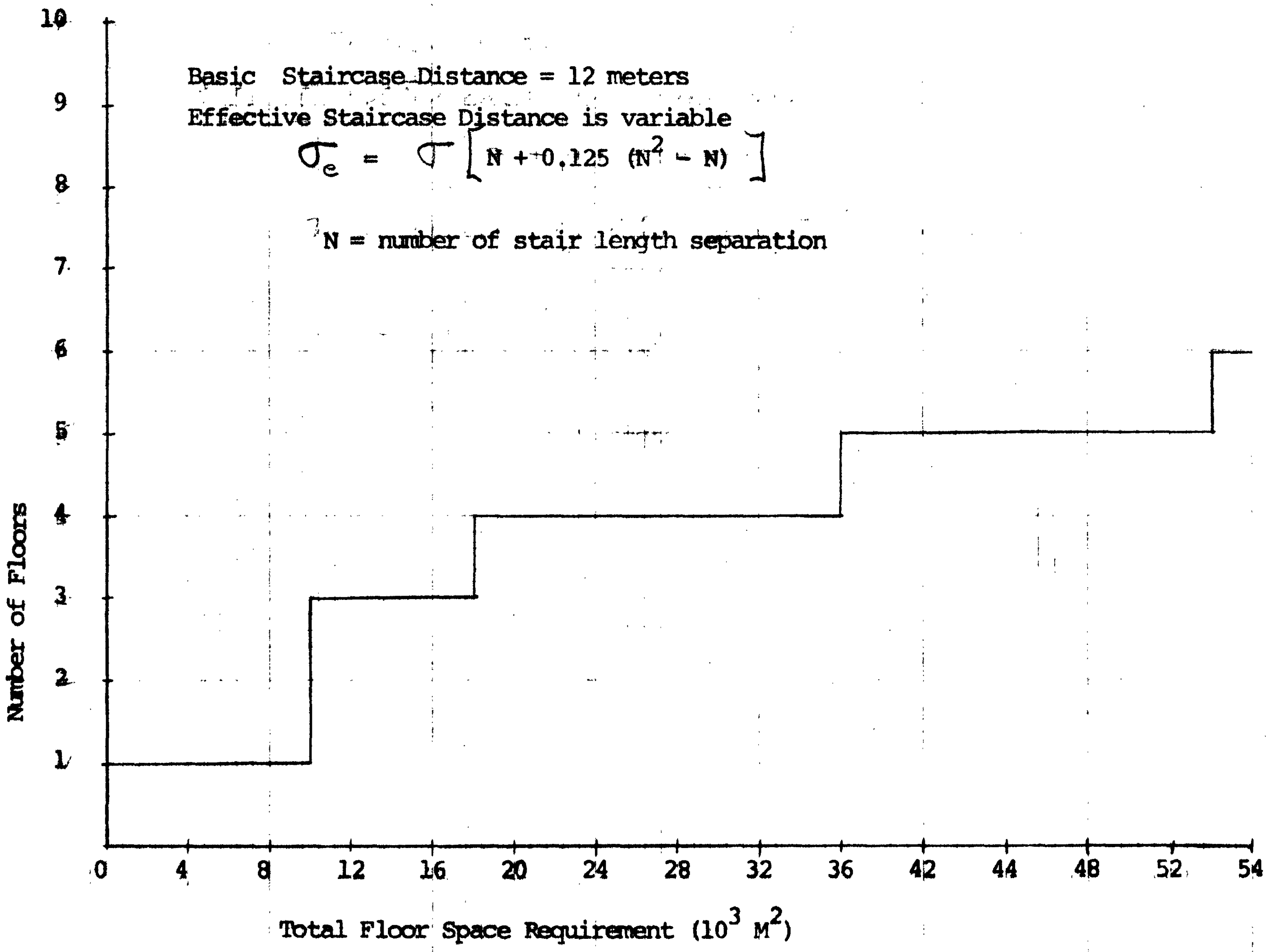

Figure 7. Number of Floors Required to Minimize Separation Distance Between Occupants in a Building (Square building, with staircase in center, 10 square meters per occupant and no internal walls).

a single floor separation by elevator, as they are to climb stairs, they are probably more willing to travel greater distance by elevator than by stairs. While the exact form of this relationship cannot be specified, at this time, it is probably safe to assume that travelling ten stories in an elevator isn't much worse than travelling one. This being the case, the most important break point in the above analysis is that at which a single floor stops being the most desirable solution. Since the optimal solution then involves more than two floors, an elevator would become desirable, and communication becomes less sensitive to building height, and land cost becomes the sole governing variable.

The most important conclusion from this analysis is that, for communication purposes, a research manager would want to limit his laboratory to a single story square building, as long as the required floor-space is less than 10,000 square meters. Above that area, the building should have at least three floors, and elevators should be used.

Interaction-Promoting Facilities

The traffic patterns in any building certainly have a direct effect on communication. They both promote chance encounters and aid in the accomplishment of intended contacts. Much of the traffic in a building results from the movement of people to and from certain types of facility which they must use during the course of a day. Examples of facilities which influence traffic patterns would be: washrooms; copying machines; coffee pots; cafeterias; computer consoles; laboratories; special test equipment, supply rooms; or conference rooms. The list could go on extensively. The types of facility that draw people to them will vary with the functions and operations of the organization. In all cases, they not only increase the occurrence of chance encounters among occupants of a building, but often aid in promoting intended contacts by providing a person with more than one reason for travelling in a particular direction.

The presence of these interaction-promoting facilities should be taken into account when locating organizational groups within a building. It is seldom possible to locate everyone on the same floor within a 30 meter circle, so one possible way to counter undesired physical separation is to locate a specific facility such as a washroom or a laboratory in such a way that it is shared by two groups whose physical separation might otherwise inhibit communication. The possibilities here are endless and require little imagination, only an awareness of the consequences of traffic patterns is needed, to analyze any given situation and locate and assign facilities and groups in ways that increase desired interaction.

AN EXPERIMENT IN LABORATORY DESIGN

Laboratory "G", the R&D department of a small chemical firm, was in 1967, planning the construction of a new research facility, thus providing an opportunity to test some of our ideas for improving communication. Discussions were held with the architects and data from earlier studies were shown to them. The architects, in turn, produced a design which minimized physical separation, while providing for privacy and making use of laboratory space assignments to offset whatever office separations were necessary.

The building was laid out in a rectangular fashion, with offices in the middles and laboratory and pilot plant space at either end (Figure 8). In the very center (room 503 in the figure) is a combination cafeteria and auditorium in which coffee is available, free of charge, all day. The purpose of this arrangement, of course, is to promote contact among those people housed in the various office clusters. Organizational groups are assigned to the small clusters of offices, on either side (e.g., rooms 617, 618, 619, and 620 are assigned to one group). Group size is generally in the neighborhood of four to eight engineers, chemists and technicians, so a group can be accomodated easily within one or two office clusters. Managers are assigned to offices in the middle (515 through 518 and 525 through 528). This was done in the belief that the organizational bond between the manager and his group would guarantee communication, but than propinquity was necessary to insure communication among the managers, themselves. Unfortunately, there are two clusters of managers' offices, separated by the lunch-room, so not all managers can be kept in contact by office location. What was done was to use the location of the managers' offices to provide integration between groups separated along the x axis in Figure 6, and then to provide for integration in the y direction by means of shared laboratory and pilot plant areas. The group occupying offices 413 through 420 shares a laboratory area with the

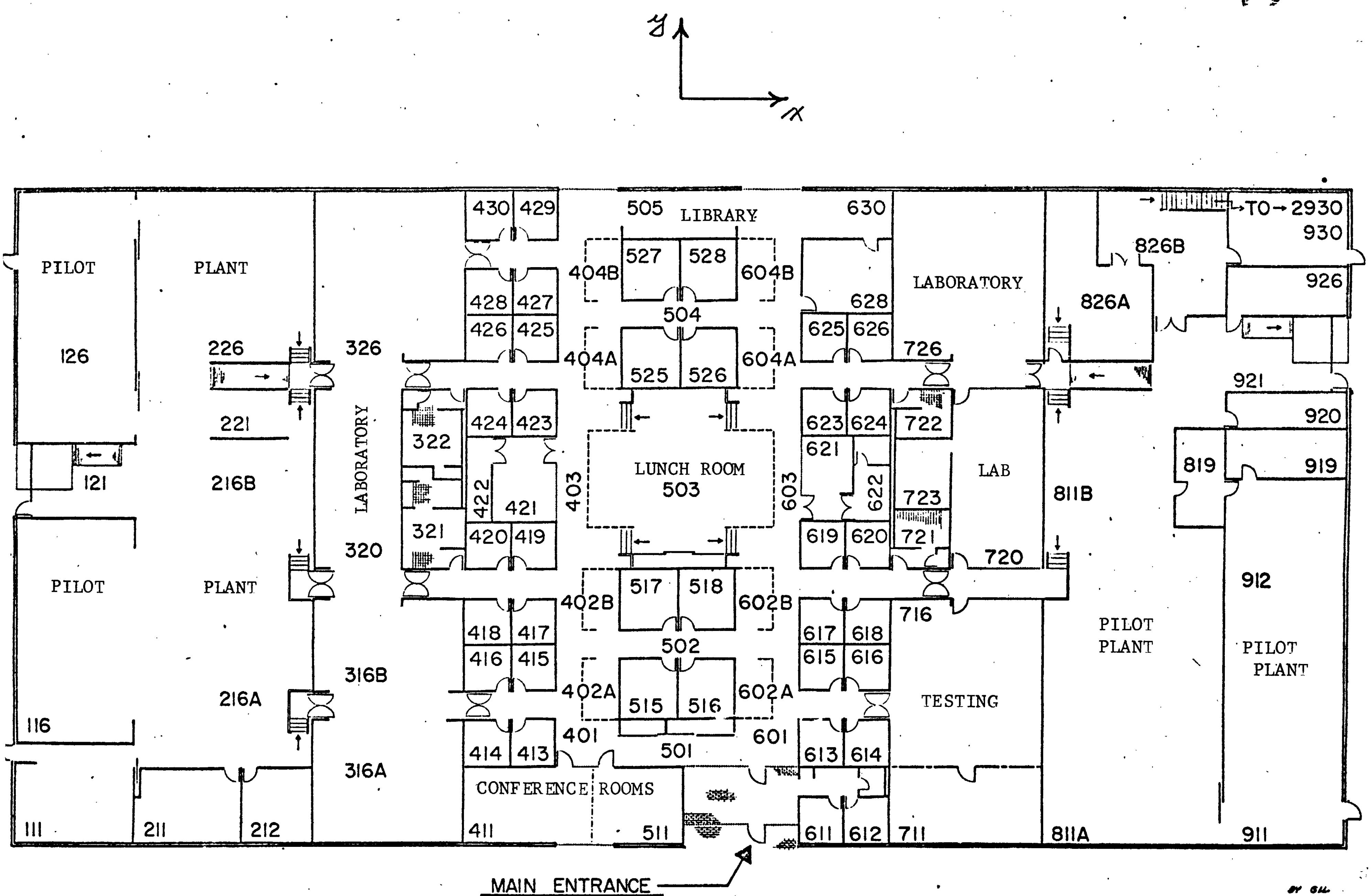

Figure 8. Configuration of the New Laboratory Facility for Laboratory "G".

group in offices 423 through 430. Their pilot plant areas are adjacent. The group in offices 623 through 626 share a laboratory with the group in 617 through 620, and so on. To provide integration along the diagonals, interaction facilities such as the lunchroom, coffeepot,[2] computer consoles (room 421) and copying machines (room 621) are all centrally located. The library is also in a key position (room 505): it is the only part of the office area provided with windows. Perhaps, while checking the weather, some one might check a current journal as well.

An additional feature of the building should provide more direct access to managers for their subordinates. Feeling that a secretary outside the boss's door might very often inhibit a subordinate from initiating informal contact with his boss, the architect located all secretaries around a corner out of sight of the manager's door (area 402, 404, 602, and 604). To provide communication between secretary and manager, a sliding window is provided on the secretary's side of the manager's office.

Laboratory "G" Before the Architectural Change. In order to determine whether the facility design accomplished its intended goals, communication measurements were made in Laboratory "G" both before and after moving into the new facility.

Prior to the opening of the new laboratory building, all employees at the main plant were located in several inter-connected structures most of which were originally built in the mid 19th Century to house a textile mill. Three R&D groups (Molding Materials; Permeable Materials and Fiberloys) were located with their laboratory space, and pilot-plant facilities, in main plant building. Under this architectural arrangement officers were grouped into clusters with substantial distances between them and with routes between clusters that traversed production and inventory areas.

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[2] Free coffee is available in the lunchroom all day, on a self-service basis.

The approximate locations in the old buildings of the three major R&D groups are shown in Figure 9. Offices of the Molding Materials and Fiberloy Groups were located on the same floor, roughly 280 feet apart. The permeable Materials group was separated from the others by two floors. A forty-foot staircase contributed part of the 110 feet separating Permeable Materials from Fiberloys as well as part of the 340 feet separating Permeable Materials from Molding Materials.

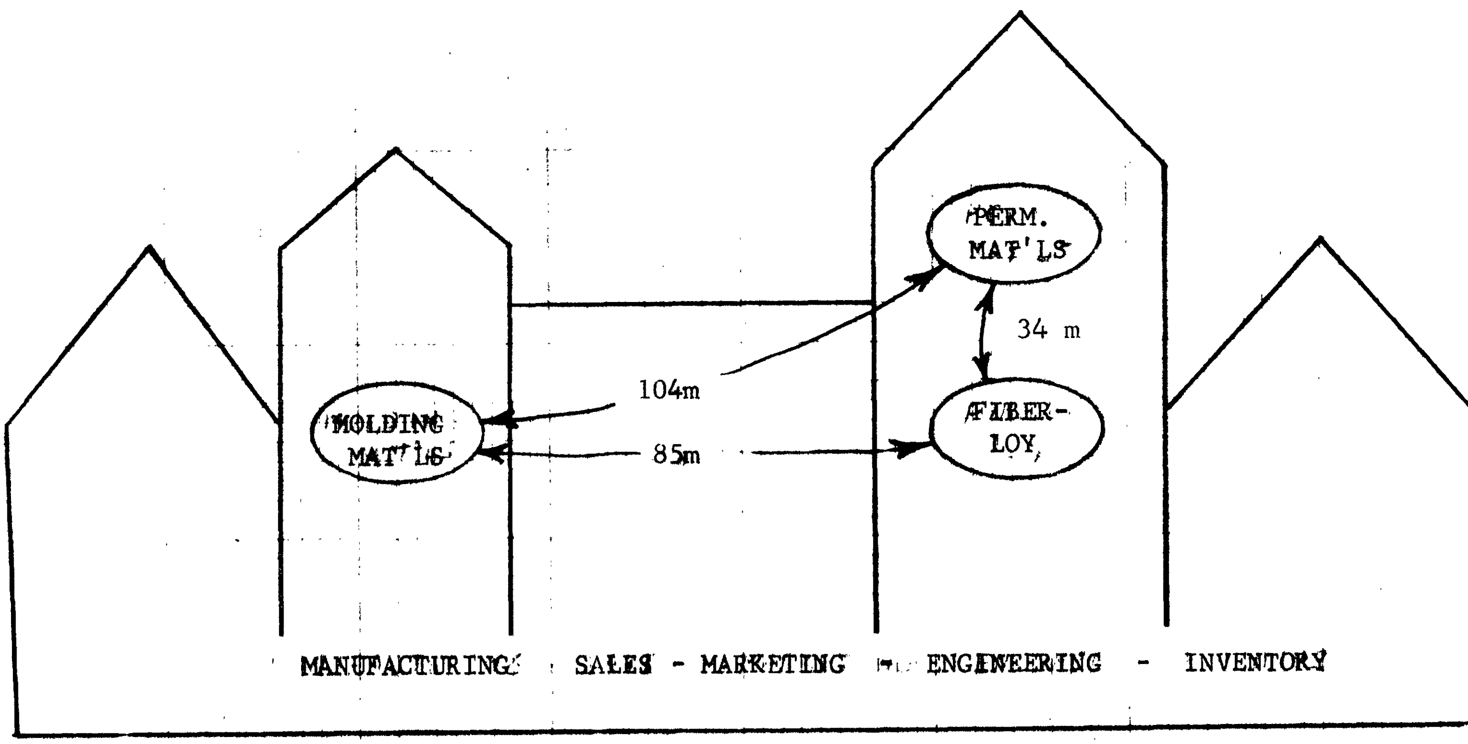

Figure 9. Approximate location of R&D groups (office and lab space at Laboratory "G" in the old buildings

The communication network for this organization, while in the old facility, certainly reflects the spatial arrangement (Figure 10). The three principal groups are not in very close communication, with Molding Materials, especially, showing the effect of its isolation.

Since the three groups are of roughly comparable size, we can compute an index of the level of communication between each pair as follows:

$$C_{AB} = \frac{\sum_{i=1}^{N_A} \sum_{j=1}^{N_B}}{N_A N_B} C_{ij}$$

where:

C_{AB} = strength of communication bond between groups A and B

C_{ij} = 1, when person i (in group A) reports weekly communication with person j (in group B) or vice versa

= 0, otherwise

N_A, N_B = number of professionals in groups A and B, respectively

The strengths of the communication bonds among the three groups is zero in two cases and o.21 in the third. Direct communication among the groups was not terribly high.

An index of intra-group communication can be constructed in a similar fashion.

$$C_A = \frac{\sum_{k=1}^{N_A} \sum_{i=1}^{N_A}}{N_A (N_A - 1)} C_{ki}$$

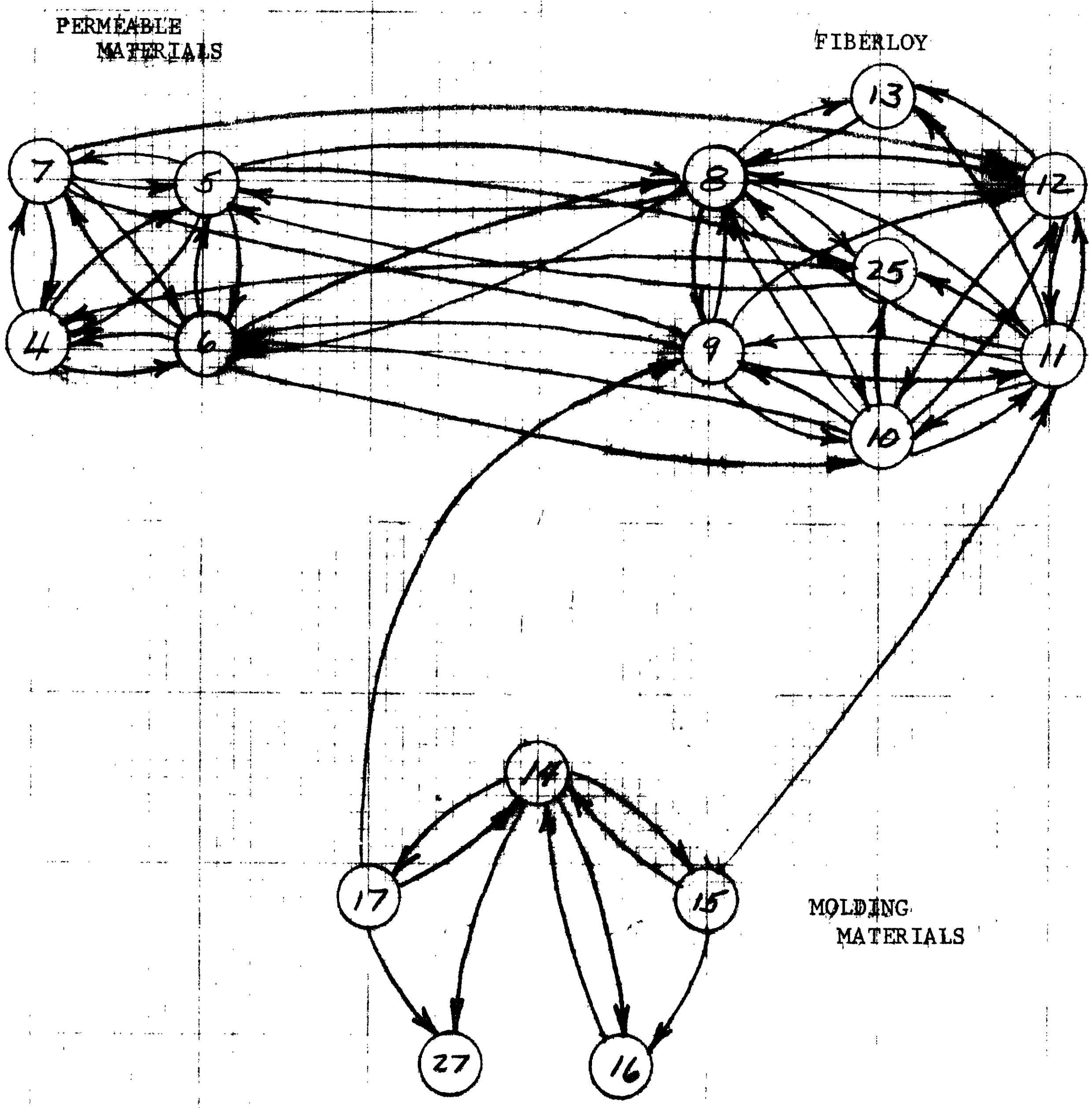

Figure 10. Laboratory "G" Prior to Architectural Change
(one or more communications per week)

where:

C_A = strength of communication index within Group A

C_{ki} = 1, when person k reports weekly communication with person 1 or vice versa

= 0, otherwise

N_A = number of professionals in group A

The strength of communication index varies considerably for the three groups, from a low of 0.30 to a high of 1.0. This can, at least in part, be attributed to the arrangement of offices in the old building, where Molding Materials was less dispersed than the other two groups.

<u>Laboratory "G" After the Architectural Change.</u> Following the opening of the new building, the three R&D groups plus one new group (formed partially out of Fiber-

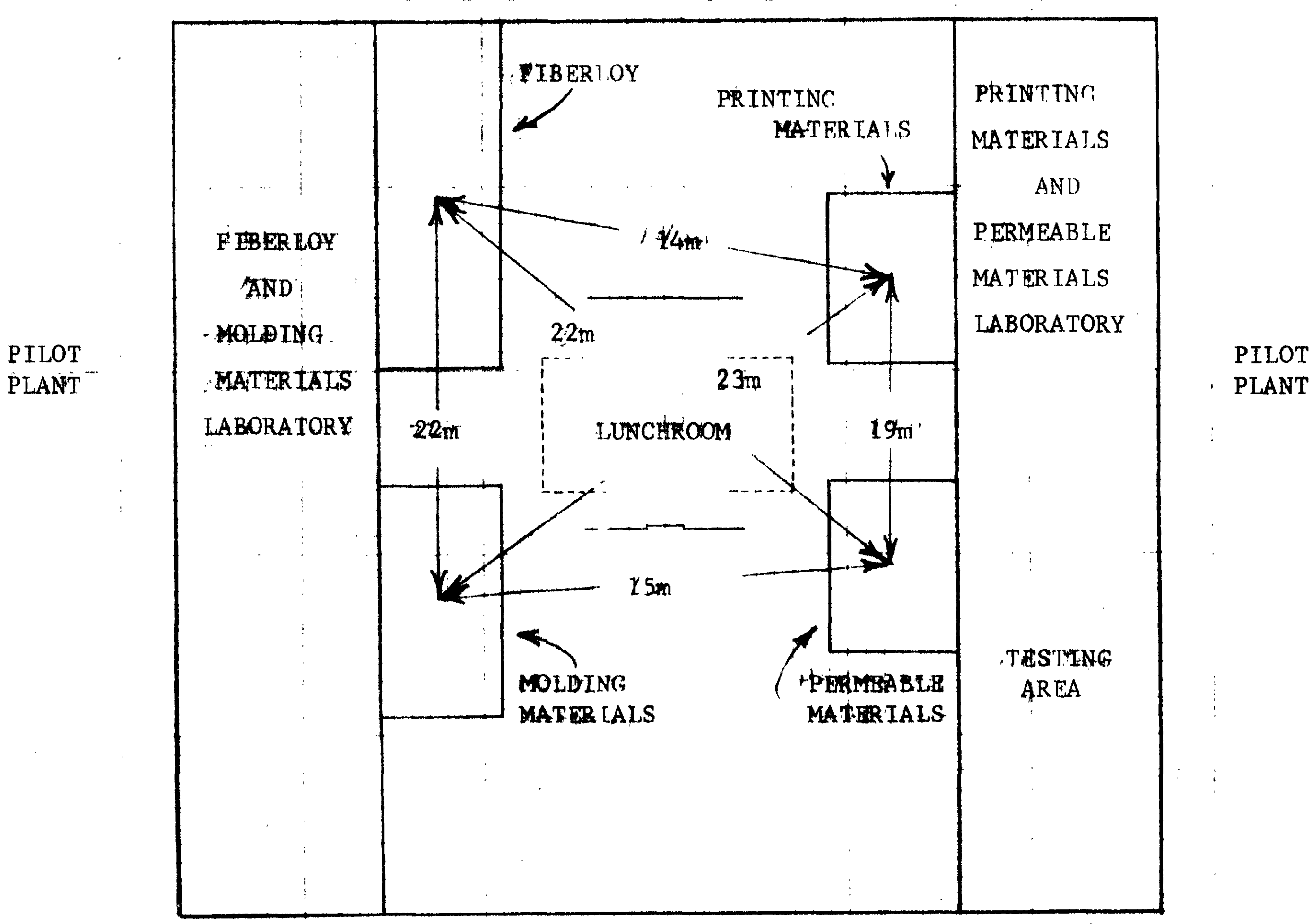

Figure 11. Location of R&D Groups in New Building

loy) were located approximately as shown in Figure 11. The distances shown in the figure are mean distances between offices, in which the location of the group managers' offices (although separated from the rest of the group) are included in the computation.

The most significant effect of the new facility is a reduction in distances between groups (Table I). The mean reduction in intergroup distance is about 73 percent. This by itself, should certainly improve communication among the groups, and in fact, it does (Figure 12). Unfortunately, there is now the additional complication of a new group (Printing Materials), plus transfers and turn-

TABLE I

Distances Between R&D Groups

separation between	and	distance in meters before	after
Molding Materials			
	Permeable Materials	104	15
	Fiberloy	85	22
	Printing Materials	--	23
Permeable Materials			
	Fiberloy	34	22
	Printing Materials	--	19
Fiberloy			
	Printing Materials	--	14

over among the staff, but there can be little disagreement that inter-group communication has increased. The number of people having weekly contact increased

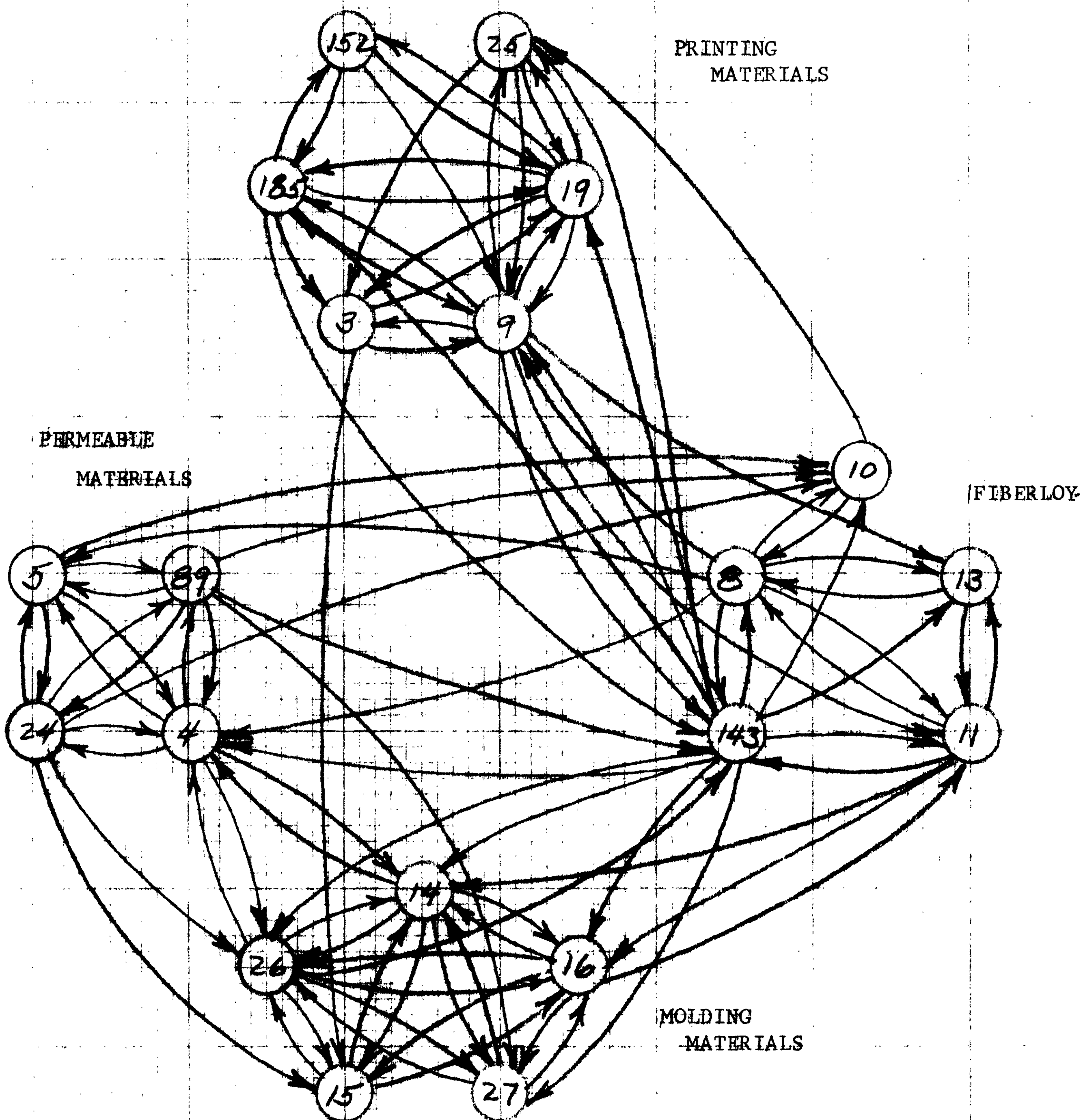

Figure 12. Laboratory "G" Following Architectural Changes
(one or more communications per week)

substantially for two of the group pairs, and remained essentially constant for the third (Table II). Another way of looking at this is to consider the number of communications between groups over a given time period (Table III).

TABLE II

Communication Bonds Among R&D Groups
(based on an average of one or more communications per potential pair per week)

communication between	and	C_{AB} before	C_{AB} after
Molding Materials			
	Permeable Materials	0	0.47
	Fiberloy	0.11	0.36
	Printing Materials	--	0.04
Permeable Materials			
	Fiberloy	0.46	0.45
	Printing Materials	--	0
Fiberloy			
	Printing Materials	--	0.36

In all three cases, there is an increase in the number of communications per potential communication pair per week. Communication among the three original groups is markedly better in the new building. At the time that the second set of measurements were made, there appeared to be a serious problem with the new R&D group, Printing Materials. This group was formed by moving several people from the Fiberloy Group, along with people moved in from other locations and some new hires. Communication between Printing Materials and Fiberloy is relatively strong, as a consequence. There is virtually no communication between Printing Materials and either of the other two groups. This situation may correct itself with time, and hopefully, the new facility will be helpful in accomplishing this.

TABLE III

Number of Communications Between R&D Groups

communication between	and	communications per potential pair per week before	after
Molding Materials			
	Permeable Materials	0.35	2.89
	Fiberloy	1.74	2.49
	Printing Materials	--	0.75
Permeable Materials			
	Fiberloy	2.77	3.81
	Printing Materials	--	0.23
Fiberloy			
	Printing Materials	--	4.89

Communication within each group should also be affected by the move into the new facility. Offices are now grouped together more closely and the layout is specifically designed to promote intra-group communication. Only one of the three groups had what could be called reasonably good communication in the old facility. Following the move into the new building, there is a marked improvement in intra-group communication, for all three groups (Table IV).

TABLE IV

Communication Level Within R&D Groups
(based on one or more communications per pair per day)

group	C_A before	after
Molding Materials	0.15	0.30
Permeable Materials	0.67	1.00
Fiberloy	0.17	0.45
Printing Materials	--	0.37

Some additional comments should be made concerning the Permeable Materials - Fiberloy link. There is some explanation for lack of improvement in that case. This link was altered not only architecturally, but also through the imposition of a "people barrier", the new Printing Development group having been placed between the Fiberloy and the Permeable offices. This barrier is particularly effective because the Fiberloy and Permeable laboratories are near their respective office areas and at opposite ends of the building. Thus, the two groups are not even forced to cross the barrier, This is shown in Figure 13 in terms of a **before-after** comparison. Clearly, the differences in the post-move arrangement may more than offset the advantage of closer distance.

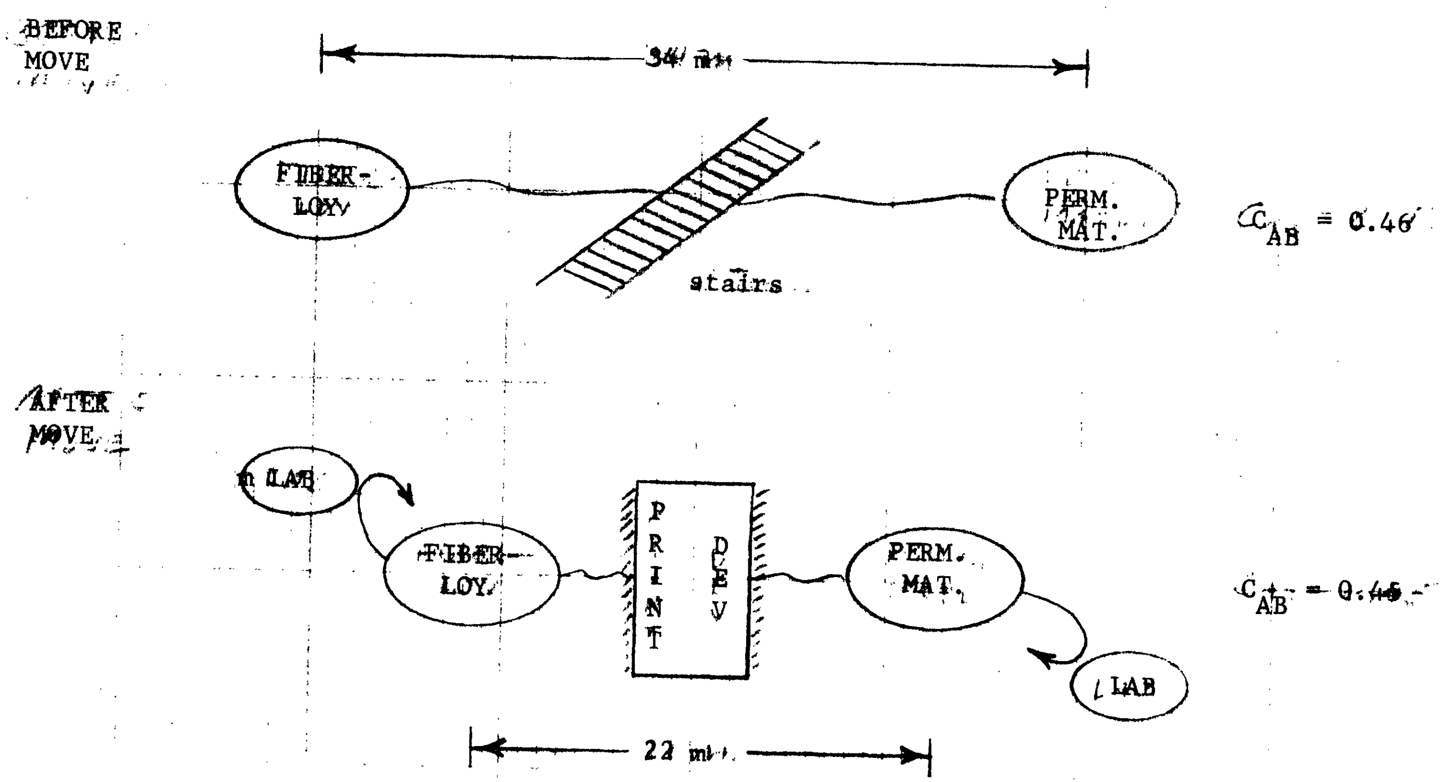

Figure 13 Before-After Comparison of the Situation Between Permeable Materials and Fiberloy

The Effect of Interaction Facilities. In this case, the interaction facilities to be examined are chemical laboratories. Each of the four groups is assigned a laboraotyr area, two groups to each side of the building. Printing Materials and Permeable Materials share a laboratory, as do Molding Materials and Fiberloy. Contrary to prediction, however, the sharing of a laboratory area did not promote inter-group communication (Table V). As a matter of fact, those organizations with both shared laboratories and adjacent offices have the weakest average communication bond. Referring back to Figure 8, communication occurs most easily in the "x" direction. This could be the result of another "facility" which tends to draw people in that direction, viz., the manager's office. Anyway, it appears, at this juncture that not very much can be said for shared laboratory space as a promoter of communication.

TABLE V

Influence of Shared Laboratory Space on Communication

	office areas adjacent-labs separate	labs adjacent office areas separate	both lab and office areas adjacent	both lab and office areas separate
mean distance between offices (meters)	13.5	--	19	20.5
mean communication bond (C_{AB})	0.42	--	0.18	0.25

The Effect of Distance Reduction. There can be little doubt that communication among the three R&D groups improved in the new facility. A question remains whether it improved in anything like a predictable manner, and whether from this study one could in turn predict the effect of future architectural changes. The changes in distance and communication can be reduced to common terms by two measures. The first is the ratio of the before and after distances:

$$\frac{D_1}{D_2}$$

where

D_1 = distance between any two groups in the old facility

D_2 = distance between the same two groups in the new facility

and the second is the ratio relating the communication indices:

$$\frac{C_{AB2} - C_{AB1}}{1 - C_{AB1}}$$

where

C_{AB1} = communication index between any two groups in the old facility

C_{AB2} = communication index between the same two groups in the new facility

The distance ratio is simply a measure of relative distance change and can theoretically vary from zero to infinity. The second ratio is the relative increase in the completeness of the inter-group connection.[3]

When the three values of $\frac{C_{AB2} - C_{AB1}}{1 - C_{AB1}}$ are plotted as a function of $\log \frac{D_1}{D_2}$ (Figure 14), they fall close enough to a straight line passing through the point (1,0) to at least arouse curiosity.[4]

[3] It represents the change in communication ($C_{AB2} - C_{AB1}$) relative to the potential for improvement ($1 - C_{AB1}$). Hence, if ($1 - C_{AB1}$) is regarded as the unfilled communication bond, then $(C_{AB2} - C_{AB1})/(1.0 - C_{AB1})$ is the relative increase in the completeness of the connection. Of course, there is only real increase in the completeness of the network when the ratio is positive; the term being phrased in the positive sense to indicate a measure of improvement in the post-move condition. In addition, the term is designed to normalize any change in C_{AB} relative to the potential and to theoretically vary from negative infinity to 1.0.

[4] If the change in communication were to result from changes in individuals' perception of distance, then the relation between relative distance and communication levels might be expected to follow the laws of psychophysical scaling. A number of investigators (Vincent, et. al., 1968; Kunnapas, 1958; Gilinsky, 1951) have in fact shown subjects' estimates of distance to be a power function of real distance. While three points are hardly enough to build a strong case, it is interesting that they should fall so close to a function of the same general form.

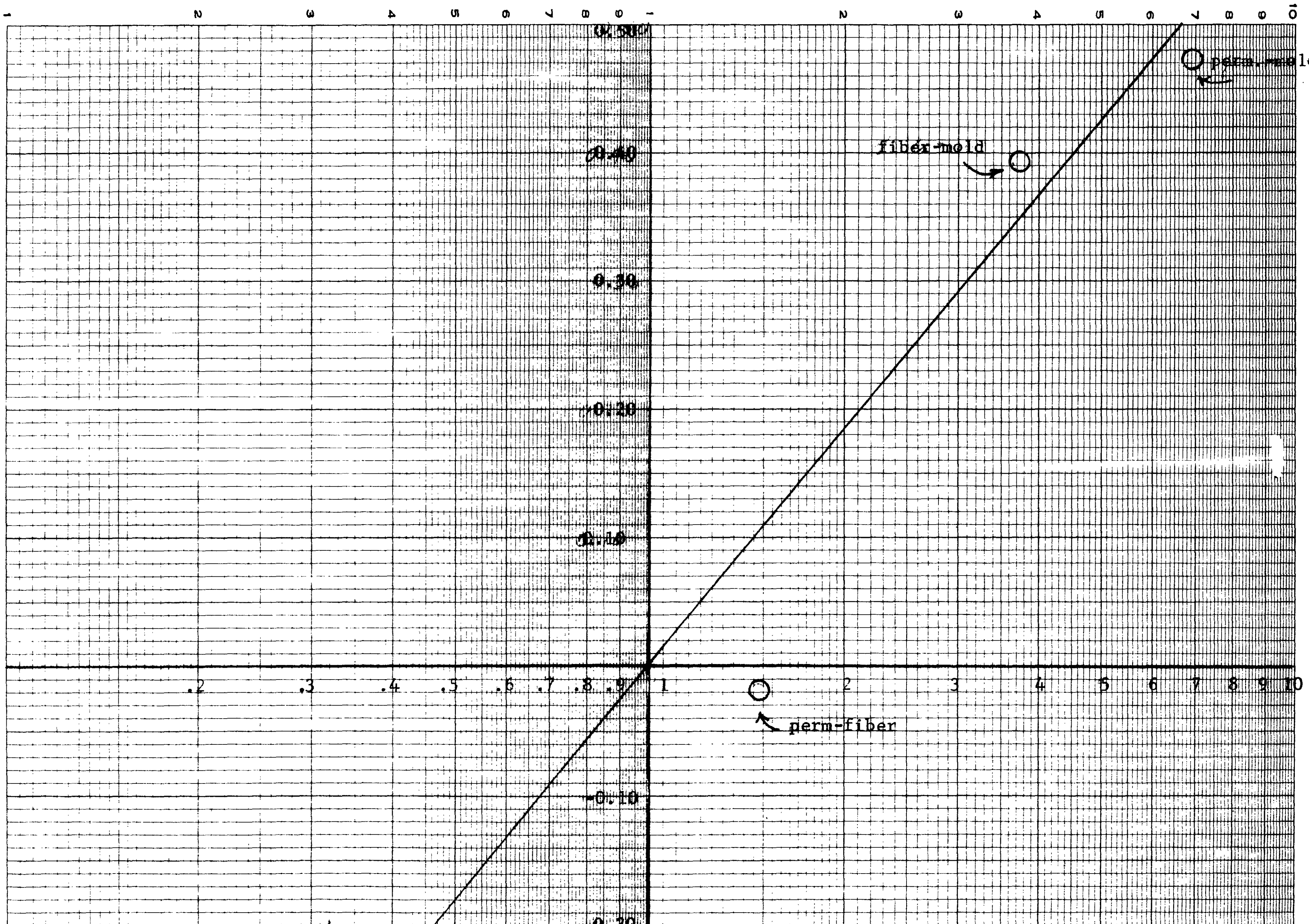

Figure 14. Change in Communication Bond as a Function of Change in Distance

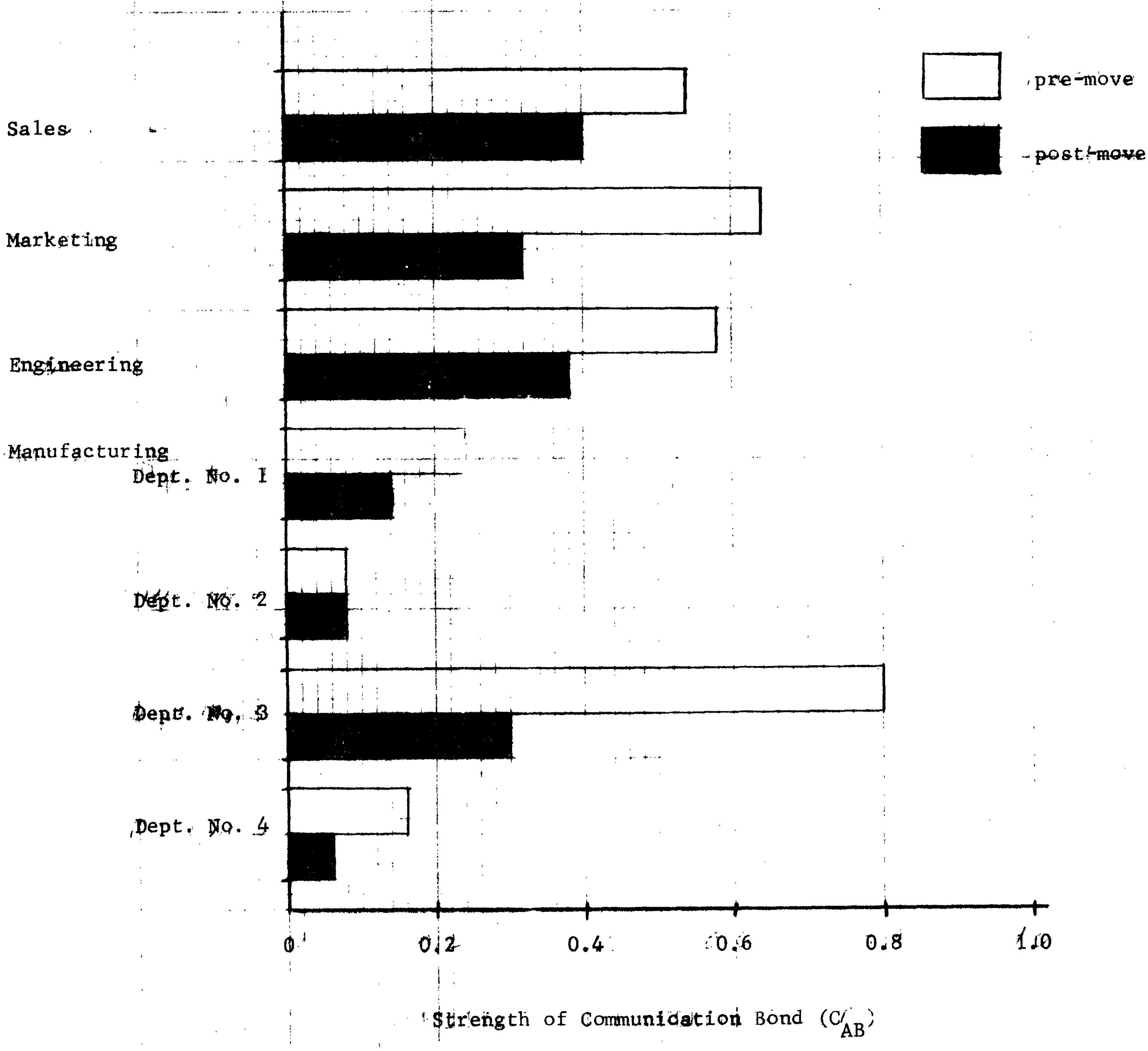

Figure 13. Communication with Other Parts of the Firm

Communication with Other Departments. In addition to the communication changes that are internal to the laboratory, i.e., the changes in linkage between R&D departments, we can also consider external communication changes. Recall that prior to the move, the various R&D groups were located in the midst of the other organizational components (Figure 9) and afterwards they were separated from them by the move into the new research center. Although the actual distances from non-R&D groups were never measured, it is clear that they all increased as a result of the move. A comparison of the communication indices, before and after the move, between the R&D laboratory as a whole and each of the other organizational groups can be examined to indicate the general effect of the separation. The data are shown in Figure 15. In all cases, except two, the communication bond decreased in the post-move period. This suggests that the move to the new laboratory generally diminished R&D's communication bonds with the other parts of the organization.

The changes which were introduced to improve communication in the R&D laboratory had the inadvertent side effect of reducing communication with other parts of the firm. There are a number of remedies that can be proposed here. The general idea is to create reasons for the movement of people between the R&D laboratory and the other departmental areas. THe firm is presently experimenting with some of these. The problem does not appear insurmountable, and hopefully external communication should be returned to its old levels without relinquishing any of the gains in internal communication.

Summary

The paper has brought together results of a number of studies of communication in R&D organizations. These studies show very clearly the way in which communication is influenced by the physical, architectural arrangement of the laboratory. Communication between individuals is very sensitive to both the horizontal and vertical distances separating them. The point at which it becomes desireable to add floors to a building was derived, as a function of required floor area. Finally, a partially successful experiment is reported, in which an attempt was made to improve communication in an organization through architectural change.

The results presented here should form the basis for further experimentation in this same manner. The possibilities are almost limitless. It only remains for some good imagination to be applied to the problem.

References

Abrams, R.A. (1943). Residential propinquity as a factor in marriage selections. American Solciological Review, 8, 288-294.

Allen, T.J. (1964). The use of Information Channels in R&D Proposal Preparation, Cambridge, Mass.: M.I.T. Sloan School of Management, Working Paper No. 97-64.

Allen, T. J. (1966). Performance of information channels in the transfer of technology, Industrial Management Review, 8, 87-98.

Allen, T.J. (1970). Communication networks in R&D laboratories, R&D Management, 1, 14-21.

Baker, N.R., J. Siegmann and A.H. Rubenstein (1967). The effects of perceived needs and means on the generation of ideas for industrial research and development projects, I.E.E.E. Transactions on Engineering Management, 14, 156-162.

Festinger, L., D. Schacter and K. Back (1950). Social Pressures in Informal Groups: A Study of Human Factors in Housing. New York: Harper.

Fusfeld, A. R. and T. J. Allen (1974), Optimal Height for a Research Laboratory, Cambridge, Mass.: M.I.T. Sloan School of Management Working Paper No. 699 -74.

Gilnisky, A.S.(1951). Perceived size and distance in visual space, Psychological Review, 1951.

Gullahorn, J.T. (1952) Distance and friendship as factors in the gross interaction matrix. Sociometry, 15, 123-134.

Hagstrom, Warren (1965). The Scientific Community. New York: Basic Books

Hare, P.H. and R.F. Bales (1963). Seating position and small group interaction. Sociometry, 26, 480-486.

Kennedy, R. (1943). Premarital residential propinquity. American Journal of Sociology, 18, 580-584.

Kunnapas, T.M. (1958). Measurements of subjective length in the vertical-horizontal illusion, Nordisk Psykologic.

Leavitt, H.J. (1951) Some effects of certain communication patterns on group performance, Journal of Abnormal and Social Psychology, 46, 38-50.

Maissonneuve, J. (1952). Selective choices and propinquity. Sociometry, 15, 123-134.

Pely, D.C. and F.M. Andrews (1966) Scientists in Organizations, New York: Wiley.

Shilling, C.W. and J.W. Bernard (1964). Informal Communication among Bio-Scientists, George Washington University Biological Sciences Communication Project, Report 16A-64.

References (Cont.)

Sommer, R. (1969). Personal Space: The Behavioral Basis of Design, Englewood Cliffs, N.J.: Prentice Hall.

Steinyor, B. (1950). The spatial factor in face to fact discussion groups. Journal of Abnormal and Social Psychology, 45, 552-555.

Strodtbeck, F.L. and H.L. Hook (1961). Social dimension of a twelve man jury table. Sociometry, 24, 397-415.

Vincent, R.J., William Brown, Robert Markley, and Malcolm Arnoult, Magnitude estimation of perceived distance over various distance.ranges, Psychonomic Science, 1968.