BASEMENT

WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

Research Program on the
MANAGEMENT OF SCIENCE AND TECHNOLOGY

Time Allocation Among Three Technical Information Channels by R&D Engineers

Thomas J. Allen, Maurice P. Andrien, Jr.
and Arthur Gerstenfeld

April 1966

#184-66
(supercedes #131-65)

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

Research Program on the
MANAGEMENT OF SCIENCE AND TECHNOLOGY

Time Allocation Among Three Technical Information Channels by R&D Engineers

Thomas J. Allen, Maurice P. Andrien, Jr.
and Arthur Gerstenfeld

April 1966

#184-66
(supercedes #131-65)

This study was initially supported by a grant from the National Aeronautics and Space Administration, (NaNsg 235-62) and since November 1963, by grants from the National Science Foundation (GN233 and GN353). Richard J. Bjelland, Stephen I. Cohen, Daniel S. Frischmuth, and William D. Putt served as research assistants during various phases of the project. The authors gratefully acknowledge the cooperation of the many companies, project managers and engineers who must remain anonymous but without whose help the study could not have been conducted.

ABSTRACT

Five government funded parallel research and development projects plus four single projects are examined to determine the manner in which engineers and scientists allocate their time, and the effect of this allocation on the outcome of the projects. The use of matched pairs of projects allows the relative evaluation of outcomes by technical monitors in the customer agencies.

In the research projects the higher rated teams spend more time than the lower rated teams in literature search and staff consulting. The percent of total time spent in three categories of information gathering (outside consultation, staff consultation, and literature search) varies significantly over the life of a project. Higher rated teams are relatively stable in all phases of information gathering while lower rated teams initially spend far more time gathering information than they do in the later stages and fluctuate more throughout the project. Subsystems characterized by greater uncertainty receive a higher percent of information gathering time than subsystems where uncertainty is lower.

INTRODUCTION

Research and development is a problem solving process depending on information inputs from the environment as well as on the stored knowledge and the ability of the personnel involved. Improvement in the flow of scientific information is an important goal of R&D management, but is dependent upon a thorough understanding of the process itself. The research reported here is concerned with the manner in which individual engineers and scientists allocate their time among three general classes of information channel (literature; personnel outside the laboratory; and personnel within the lab) and examines possible effects this allocation may have on the conduct and performance of the R&D project on which they are engaged.

In order to obtain a performance evaluation for each information channel, instances were sought in which the same problem is attempted by two or more research groups.[1] In this way, a comparison can be made between the information sources leading to specific solutions. The fairly common practice of the Department of Defense and the NASA to award parallel study contracts during the early phases of R&D provides an opportunity for control over the effect of varia-

---

[1] The idea of studying parallel R&D projects as a quasi-experimental situation was suggested by Donald Marquis, who also helped in developing some of the research procedures.

tions in the problem substance. The data presented are from five parallel contracts involving ten R&D groups and four single projects.

The major hypotheses of this study concern the variation in time allocated among the three information channels over the course of an R&D project. Specifically, it is hypothesized that:

1. Literature will be used more heavily at the initiation of a project and will be replaced by personnel outside the laboratory (principally vendors) as the principal information source as the project progresses.
2. Sources within the lab will be employed intermittently over the course of a project.
3. Teams conducting an extensive information search at the beginning of a project perform better.
4. The extent to which the lab's technical staff is used as an information source will be <u>directly</u> related to performance.
5. The extent to which the team relies upon individuals outside of the laboratory organization as information sources will be <u>inversely</u> related to performance.
6. Subsystems with a high degree of uncertainty (uncertainty is operationally defined) receive greater attention in terms of time spent on information gathering than those having a lower degree of uncertainty.

METHOD

Once a parallel project has been located, its work statement is obtained, and analyzed and factored into a reasonable number of subproblem areas (generally subsystems). The breakdown is then checked with the technical person who prepared the work statement, and data collection forms based upon it are designed. After all data have been collected from the contractors, the technical monitor is revisited and asked to provide a confidential evaluation of each lab's performance. Data are gathered by four means: (1) time allocation forms, indicating the amount of time each engineer spends on the job in several activity categories; (2) before and after interviews with the individual engineers; (3) periodic tape recorded progress reports by the project manager; and (4) solution development records.

Time allocation forms supported by data from Solution Development Records are the principal source of the data here under consideration. On these forms, respondents are asked simply to record the amount of time spent each day in each of four activity categories: time spent in literature search; time spent in consultation with technical experts within the laboratory, but not assigned to the project; time spent in consulting with experts outside the laboratory organization; and time spent in analytic design or active problem solving.

The Solution Development Record provides a means of following the progress of an R&D project through its subsystem design changes, and has been described in detail elsewhere (Allen, 1966).

Description of the Projects

The five parallel projects under consideration involved the following general problems:

1. The design of the reflector portion of a rather large and highly complex antenna system for tracking and communication with space vehicles at very great distances.
2. The design of a vehicle and associated instrumentation to roam the lunar surface and gather descriptive scientific data.
3. The study of possible mission profiles for manned flights to another planet.
4. The development of a detailed mathematical cost model yielding complete R&D and operational program cost estimates of space launch vehicle systems.
5. An investigation of passive methods for transfer of modulation between two coherent light beams.

In addition data from four single project teams, whose parallel partners failed to submit time forms will be analyzed. These four projects involved the following general problems:

1. The preliminary design of a special-purpose manned spacecraft for cislunar missions.

2. The preliminary design of an earth orbiting space laboratory.

3. The development of a mathematical model for an interplanetary transportation system.

4. The development of a container for cryogenic fluids.

Unit of Analysis

Man-hours devoted to an information channel is the unit of analysis employed. (cf. Menzel, 1960). Since engineering man-hours expended is quite closely correlated with cost on such projects as these, the choice of unit provides a measure not only of the relative extent to which channels are used, but also of a major portion of the relative expense involved in such use.

Data Analysis

In comparing time allocated to information channels across projects, the variables in question are represented as percentages of total time. This serves several purposes. First of all, the projects are of varying size and using actual hours to represent the variables would give undue weight to the larger projects. Secondly, percentage representation overcomes the problem of incomplete data in any section of a project.[2] Finally, the total number of engineers reporting varies from team to team within projects; and percentage representation allows intraproject comparison. Percentages for any given

---

[2] Due to occasional failure of engineers to maintain their time allocation forms.

2. The practicability of [illegible] laboratory.

3. The development of [illegible] interplane- tary [illegible] system.

4. The development of [illegible].

Unit of Analysis

Man-hours devoted to [illegible] results retrieved [illegible] Mooers (1951) [illegible] [illegible] the [illegible] [illegible]

[illegible]

time period of a project are the ratio of the total time spent by all individuals on the variable in question to the total time reported by all individuals.

RESULTS

Relations Between Performance and Time Allocation

Higher and lower rated project teams are determined on the basis of the government technical monitors' performance ratings. The percent of time spent in total information gathering, and in literature search, outside consultation, staff consultation, and analytic design are averaged for the higher and lower rated teams. The results in Table I show that on the average the higher rated teams spend more time in information gathering. Literature search and staff consultation show the greatest difference.

Hypotheses 4 and 5, which are based upon the results of Allen's (1964) study of R&D proposal competitions and on Shilling and Bernard's (1964) findings that the use of outside consultants by industrial bio-scientists was negatively related to eight "measures of laboratory productivity and efficiency", are only weakly supported by the evidence. Higher performing teams spend more time in discussions with the technical staff and lower performers spend more time with external sources. The difference between high and low performers, however, is in neither case statistically significant.

Table I

Time Allocation by Function
(Five Parallel Sets of R&D Projects Plus Four Single Projects)

	Five Higher Rated Projects	Five Lower Rated Projects	Total for five parallel sets	Total for 14 projects
All information gathering	19.31	14.74	17.02	15.43
Literature search	8.46	5.67	7.06	6.70
Consultation with external information sources	4.60	4.85	4.72	4.22
Consultation with technical staff	5.77	2.23	4.00	4.51
analytic design	73.70	72.94	73.32	76.10
other	7.47	14.31	10.89	8.47

Necessity of Analysis Over Time

Figure I shows that the time spent in gathering information varies considerably over a project's life and the components that make up the total time spent gathering information vary in a somewhat different manner, although the interaction term is not statistically significant. Information gathering is greatest in the initial time period. Literature search and outside consulting make up the large component in this state, corraborating the general belief that initially on a new project engineers conduct an extensive literature search and seek out possible

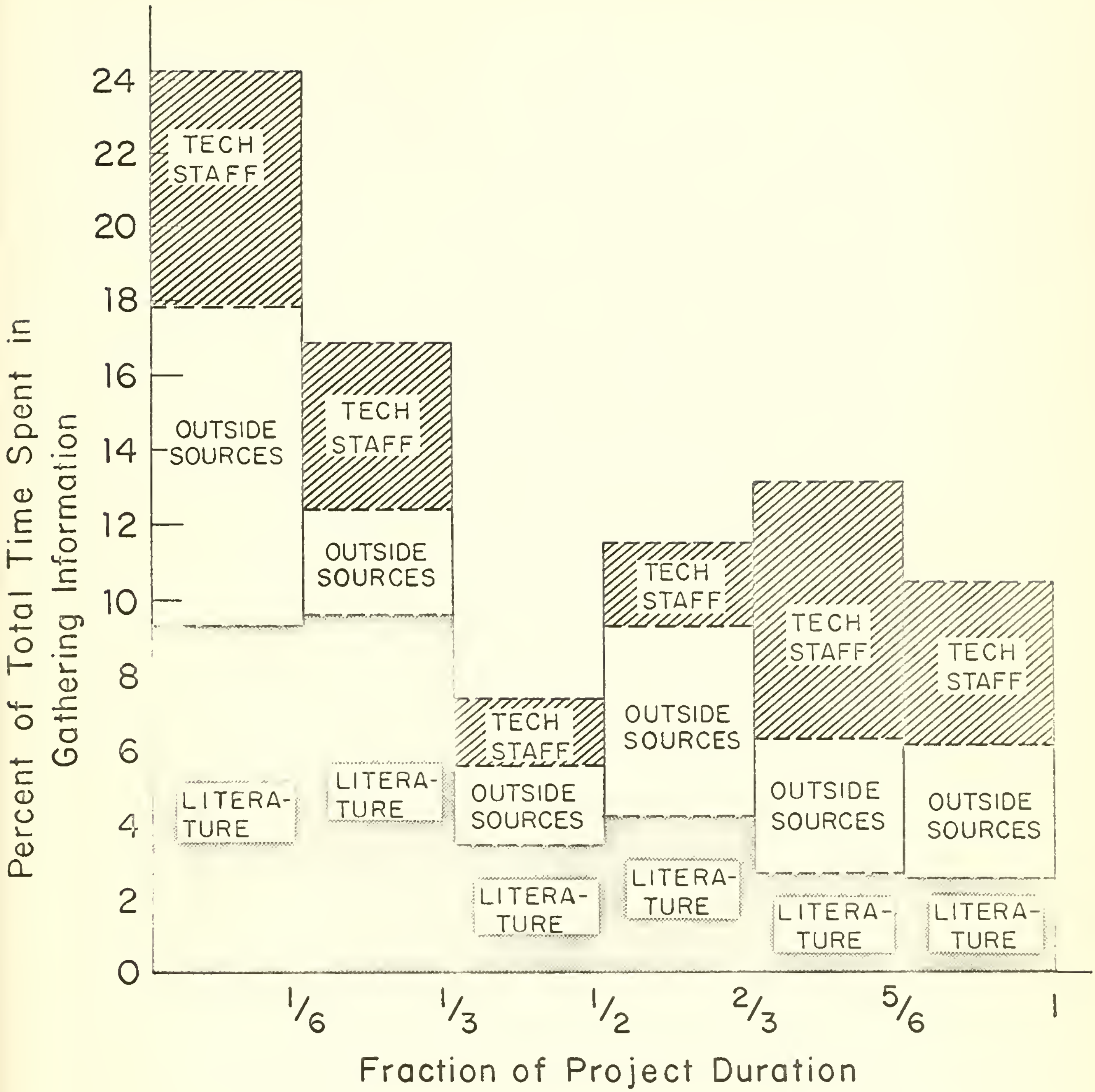

Figure I. Percent of total time which is spent in gathering information as a function of project life span (Averaged for five matched pairs of R & D projects plus 4 single projects)

suppliers for ideas as well as components.

While literature search is the primary information gathering tool in the initial stages, it quickly decreases as the projects progress and is replaced in importance by person-to-person communications. Outside consulting is relatively high initially, but generally speaking is an important factor in all phases of the projects. Staff consultation is greater at the beginning and end of the project. This seems to indicate that the internal technical staff is used least at the midpoint of a project and largely utilized during initial and final stages.

Performance Relations Over Time

Total Information Gathering. When the teams are again divided on the basis of high and low performance, it is apparent (Figure 2) that poor performers spend more time in the initial stage of a project than higher rated teams, but less time in the final stage. The results are exactly counter to hypothesis 3 (page 2). It was predicted that those teams which conduct an extensive information search at the outset of a project would perform better as a result. The results, however, lead to the conclusion that the teams performing the more extensive information search were less well prepared at the outset, perhaps through lack of experience or failure to bring themselves up to an adequate state of knowledge prior to contract initiation, and that the more intense information gathering in the initial period fails to

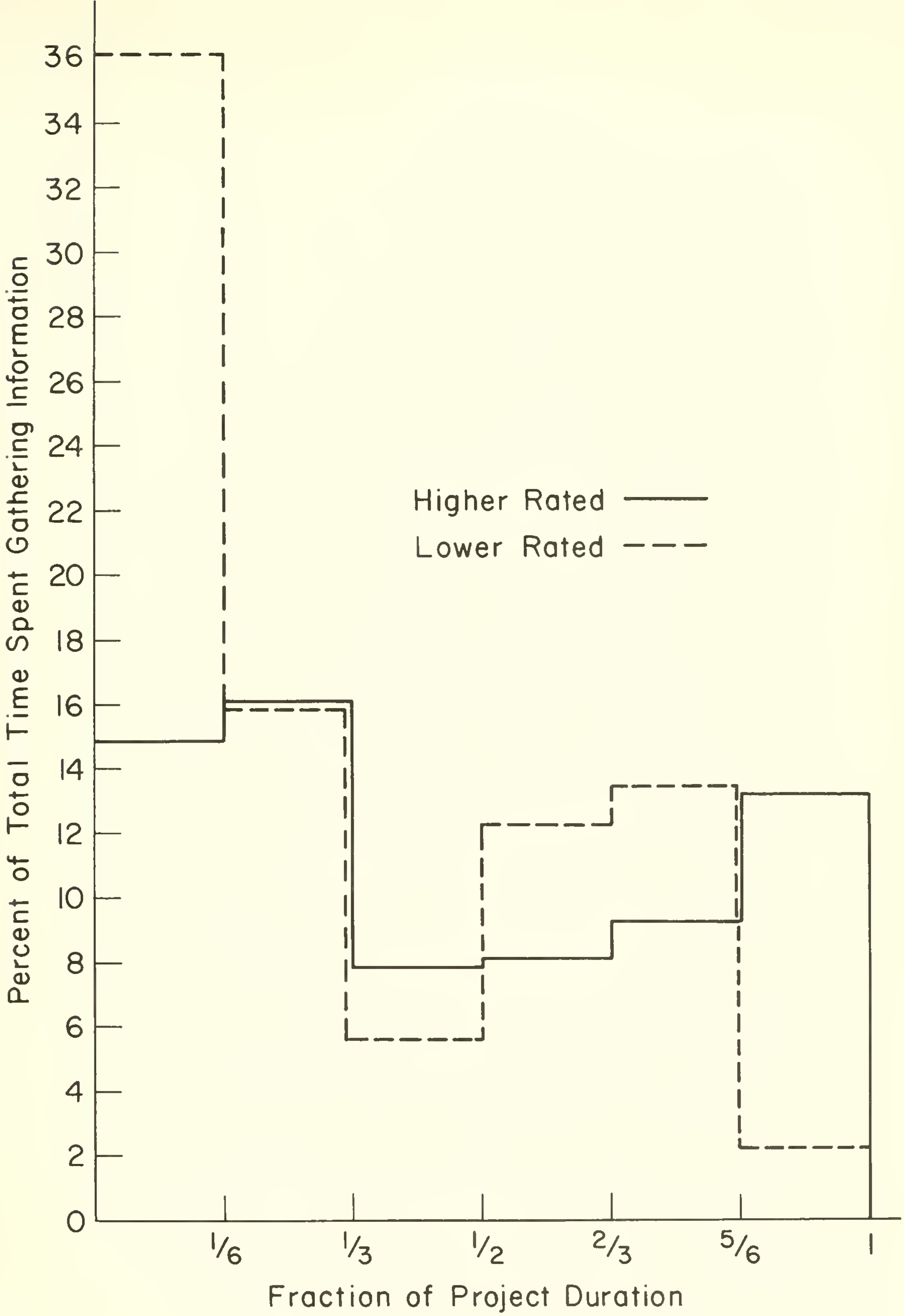

Figure 2 Comparison of percent time spent by higher and lower rated project teams in information gathering (Averaged for five matched pairs of R & D projects)

compensate for this deficiency. As the project progresses, the higher rated teams spend an almost constant level of effort in gathering information, and end with a surge in the final period. The lower rated teams, on the other hand, taper off markedly after the initial period and perform hardly any information gathering in the final period. The difference in the final period may well reflect the effects of premature closure on the part of the poorer performers. Since all of the projects were studies rather than hardware developments, it may well be beneficial, in such cases, to remain receptive to new ideas right up to the time when the study report is delivered to the customer. The better performing teams apparently behaved in this manner, actually devoting an increased amount of time to information gathering in the final period.

Outside Sources. Higher rated teams are far more consistent over time than lower rated teams in their use of information sources outside the laboratory. The higher rated teams seem to stay closer to the ideal of bringing outsiders "on board" early and maintaining close contact throughout the project's life, not just when difficulties arise. In this way both parties are kept sufficiently aware of progress made by the other, and such difficulties as interface incompatibility are reduced. The lower rated teams, on the other hand, do not maintain close liaison with the external sources, and periodic spurts of heavy communication fail to compensate for the lack of a continuous relationship. (Figure 3).

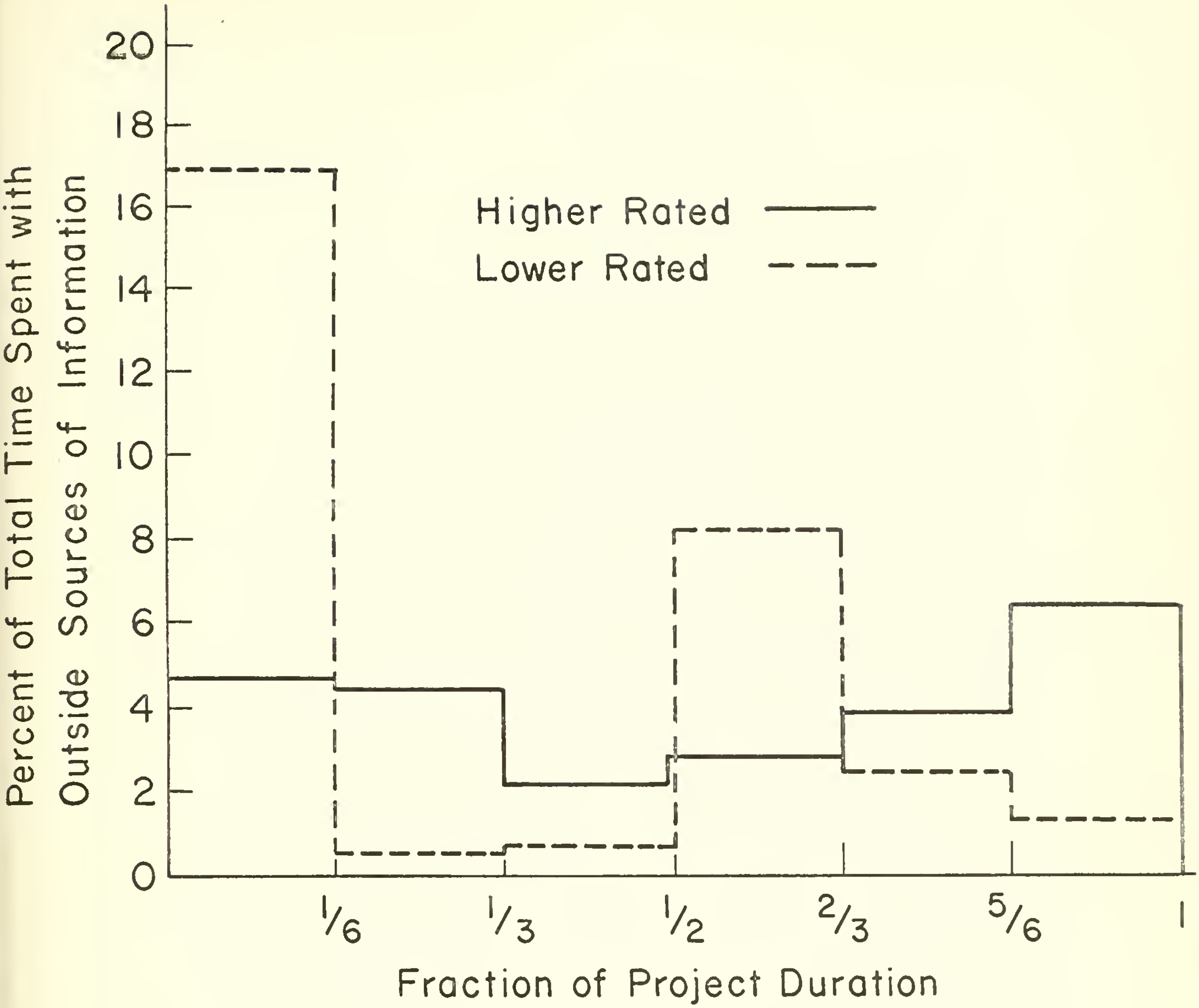

Figure 3 Comparison of percent time spent by higher and lower rated project teams in consulting with sources of information outside the laboratory (Averaged for five matched pairs of R & D projects)

<u>Technical Staff</u>. Although the time spent with this channel is the smallest reported (2.23% for losing teams and 5.77% for higher rated teams), it is a very important source of technical information. Staff specialists are often called upon to solve critical problems beyond the capability of team members. Again the time pattern follows that established for outside sources -- consistency over time by the higher rated teams and fluctuation by the lower rated teams.

The higher rated teams utilized staff assistance from the beginning of the project to the end and maintained contact with this source of information throughout the duration of the project (Figure 4). The lower rated teams call for staff assistance at the beginning of the project, then drop to very low utilization of staff in the middle (third and fourth sextile, .43). Toward the end, perhaps recognizing difficulties the staff is again called in. A practice often employed by industry is to utilize staff assistance as an information source only when difficulties arise. The major drawback of this procedure is that it is often too late for the staff to be of appreciable assistance. This research confirms the fact that higher rated teams utilize the staff quite evenly throughout the duration of the project which keeps this valuable information channel open during both good and bad times, possibly forestalling some difficulties before they have time to become established.

<u>Literature Search</u>. Although the differences between higher and lower rated teams are not significant, the general pattern is similar

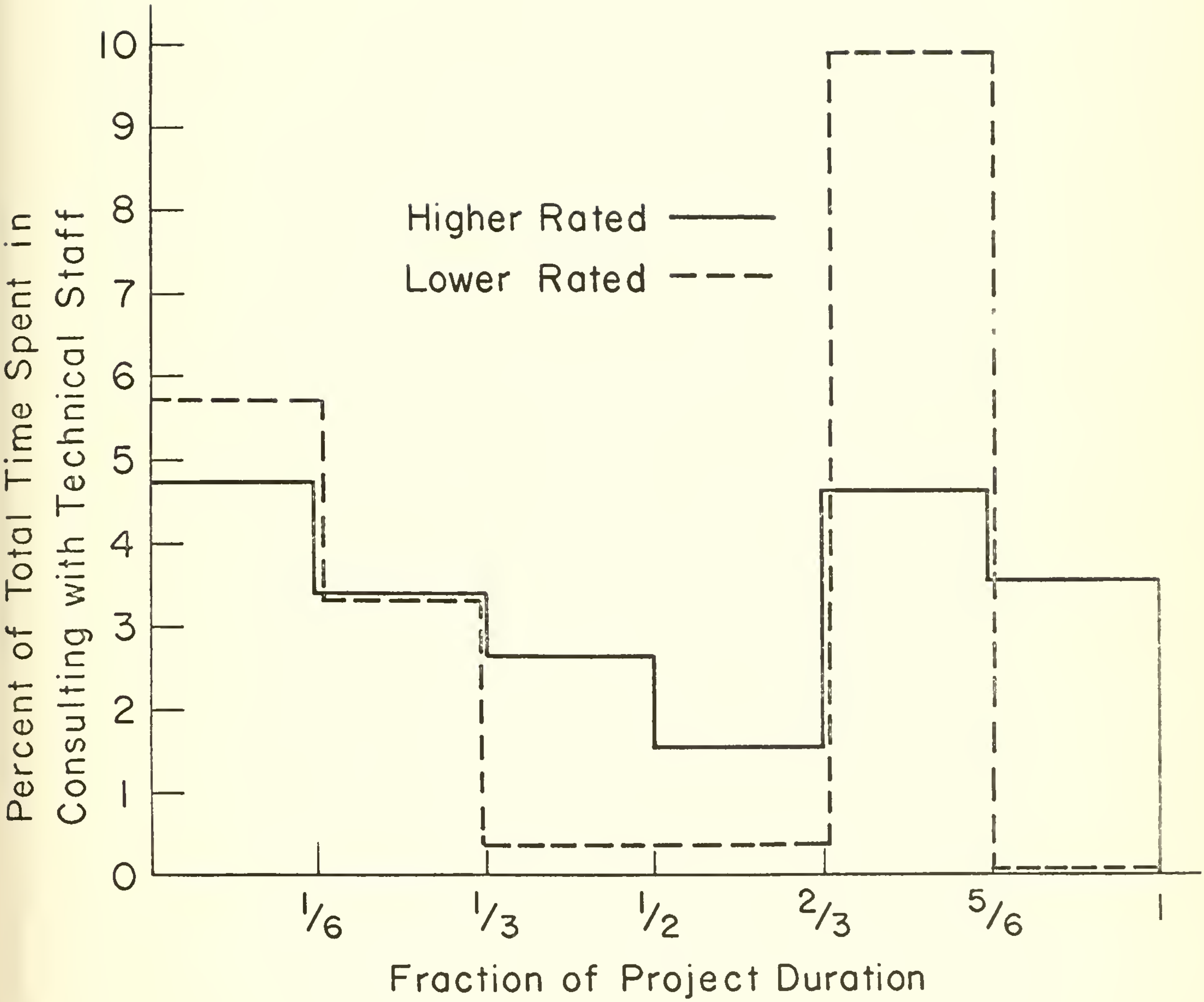

Figure 4 Comparison of percent time spent by higher and lower rated project teams in consultation with the lab's technical staff (Averaged for five matched pairs of R & D projects)

to that for the other information channels. Higher rated teams remain fairly steady and lower rated teams fluctuate. The lower rated teams, however, are not quite as erratic as in other information activities, showing instead a rather steady decline as the project progresses (Figure 5).

Uncertain Subsystems

When there is a great uncertainty about the outcome of the solution approaches under consideration, engineers will either seek out new approaches or try to reduce the uncertainty in the old ones through attainment of greater knowledge. In either case information is gathered to aid their decision. Therefore, it was hypothesized that subsystems characterized by high uncertainty would require more information gathering than those in which uncertainty is low.

To test this, it is first necessary to define and measure uncertainty. At least two estimates of uncertainty are available from the data. From the Solution Development Record, the average weekly value for Δp can be determined for each subsystem.[3] A large value of Δp should indicate high uncertainty but in some cases several alternatives are carried at a low level throughout most of the project with none achieving clear dominance; in such cases Δp can be

---

[3] Engineers provide a weekly estimate, on the Solution Development Records, of the subjective probability that each alternative considered as a possible solution will in fact be finally chosen as the solution. The measure Δp is the total change in probability level for all alternatives in a given subproblem (Allen, 1966).

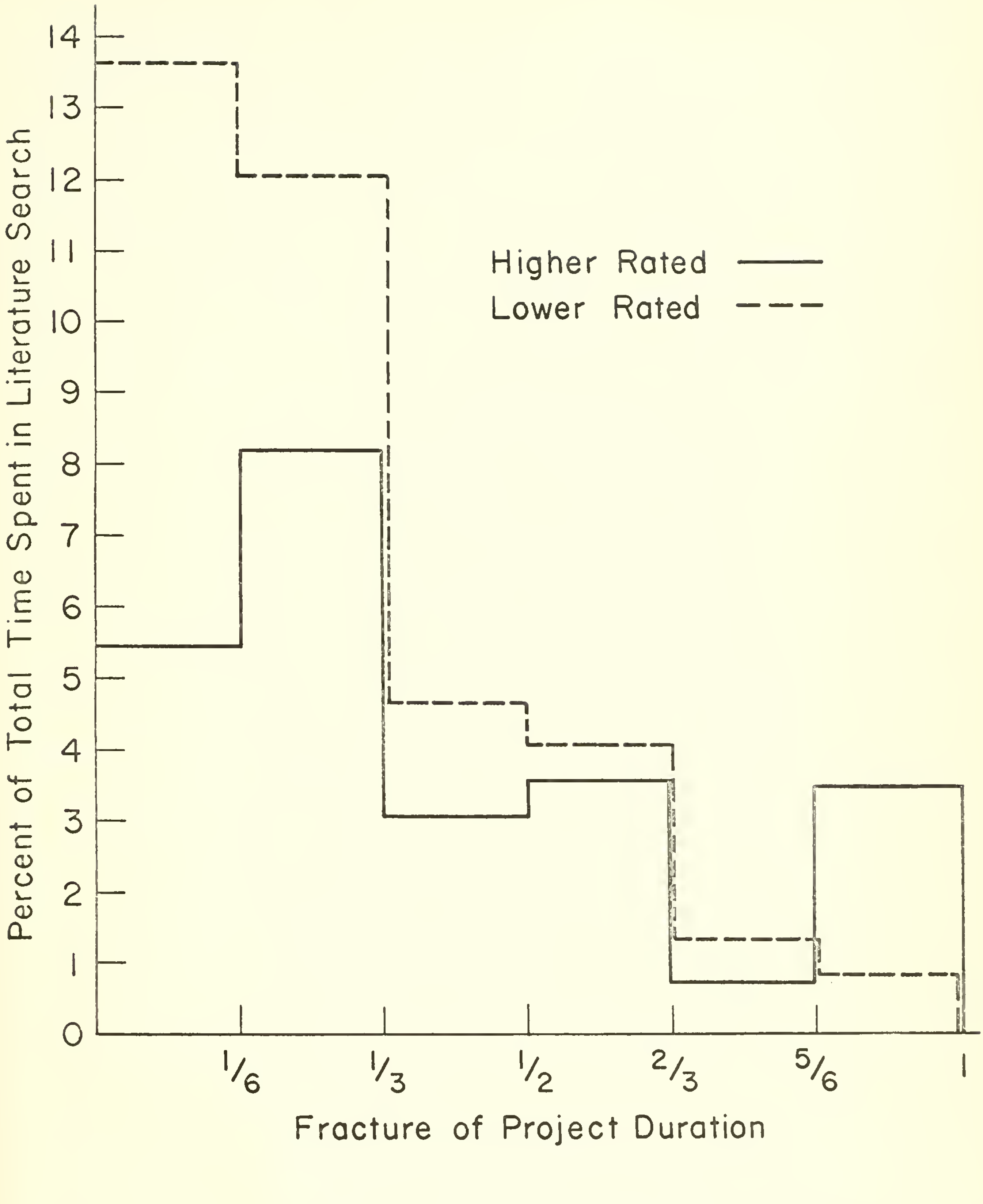

Figure 5 Comparison of percent time spent by higher and lower rated project teams in literature search. (Averaged for five matched pairs of R & D projects)

very small and yet the uncertainty is obviously high. A more reliable and sensitive measure appears to be the number of weeks the winning alternative maintains a probability less than 0.7 on the Solution Development Record. If the winning alternative is reported at a probability of 0.7 or higher throughout most of the project, the subsystem is one with a relatively high degree of certainty. Conversely, if the probability of acceptance exceeds 0.7 for only a small portion of the project, this would indicate uncertainty relative to the design of the subsystem.

Uncertain subsystems are thus defined in the following two ways: (1) Those whose final solution maintained a 0.7 or higher probability for a number of weeks which was less than the average for the project. (2) Those with a weekly Δp greater than the average for the project.

The three operations research projects and one of the other projects, which was oriented more toward basic research than development, are omitted from this analysis because in these instances subsystems are not clearly defined, and relative uncertainty is therefore impossible to determine. In each of the other two projects, it is possible to identify thirty-one individual subsystem designs. There is some overlap among individuals in their responsibility for subsystems; in these cases assignment is made equally to each. This is a conservative procedure which results in a general weakening of correlations for the subsystems affected. In the case of one parallel program the overlap prevented identification of responsibilities for subsystems so these

data are not included. For the basic research project where subsystem identification was not clear, the laboratory that showed greater uncertainty over its approaches spent 41.10% of its time in information gathering. The laboratory that was more certain over its approaches spent 20% of its time in information gathering.

With these limitations noted, the percent of information gathering devoted to each subsystem is compared with the project average. Figure 6 shows the results of chi-squared tests of the hypothesis for each of the definitions of an uncertain subsystem.

The results indicate rather strongly that engineers allocate more time to information gathering when they are working on problems of higher uncertainty. This being the case, subsystem uncertainty measures should be determined at project initiation, so that engineers responsible for subsystems with the higher degrees of uncertainty may be provided with greater ease of access to information channels. Total information gathering should be planned, budgeted and allocated on the basis of subsystem uncertainty measures. Literature access in the form of information retrieval systems and library assistance should be readily available to these subsystem engineers. Provision should be made for assigning consultants from the technical staff to such subsystems at an early enough stage to avoid the apparently poor and intermittent contacts observed on the poorer performing projects (figure 4).

Certainty based upon number of weeks in which final solution exceeded 0.7 probability of acceptance.*

Percent of Total Time Spent in Information Gathering		uncertain subsystems	certain subsystems
	High	12	6
	Low	3	9

$X^2 = 5.01$
$p < .05$

probability of these results occuring by chance are less than 0.05.

*N reduced by one as a result of discarding one subsystem which fell on the median of the uncertainty measure.

Certainty based upon weekly probability change.

Percent of Total Time Spent in Information Gathering		uncertain subsystems	certain subsystems
	High	13	6
	Low	4	8

$X^2 = 3.60$
$p < .10$

probability of these results occuring by chance are less than 0.10.

Figure 6. Proportion of time devoted to information gathering as a function of subsystem certainty.

CONCLUSIONS

Five pairs of government funded parallel research and development projects and four single projects are examined to determine how their engineers and scientists allocate time, and the effect of this allocation on the outcome of the projects. The use of matched pairs of projects allows the relative evaluation of outcomes by technical monitors in the customer agencies.

Three relationships are investigated: the percent time spent in three information gathering activities as a function of the phase of the project; the relation of time allocation patterns to performance; and the correlation between degree of uncertainty in a subsystem and the amount of information gathering devoted to that subsystem.

The percent of total time spent in all phases of information gathering varies significantly over the duration of projects. When the activities are measured over time, a clear relation with performance emerges. Higher rated teams are more consistent over the duration of the projects in all phases of information gathering, while lower rated teams initially spend more time gathering information than they do in the later stages and fluctuate more throughout. Literature search by lower rated teams is regular in its declining use from the beginning to the end of projects. Staff activity for lower rated teams drops sharply in the middle of the project suggesting the beneficial effects of more continuous contact with the internal staff.

These results hold for two methods of computing percent time spent in any activity.

The time of R&D engineers is a most valuable commodity. Much of this time is spent in seeking and gathering needed technical information. Certain procedures should be designed to increase the efficiency of this search in all instances, but where a choice must be made, steps should be first taken in areas where the problem is most critical. The present research indicates that one mechanism for determining such criticality is an estimate of the relative uncertainty of solution of each subproblem. Since more uncertain subproblems are in greater need of technical information, the engineers assigned to such subproblems should be provided special assistance in gathering needed information.

REFERENCES

Allen, T. J. Utilization of Information Sources During the R&D Proposal Preparation.. Cambridge: M.I.T. Sloan School of Management Working Paper No. 97-1964.

Allen, T. J. Sources of ideas and their effectiveness in parallel R&D projects. in H. D. Kerner (ed.) Research Program Effectiveness. New York: Gordon and Breach, 1966.

Andrien, M. P., Jr. The Utilization of Technical Information in Parallel R&D Projects. Unpublished S. M. thesis, M.I.T. Sloan School of Management, 1965.

Menzel, H. Review of Studies in the Flow of Information Among Scientists. New York: Columbia University, Bureau of Applied Social Research. 1960. (mimeo)

Shilling, C. W. and Jessie Bernard. Informal Communication Among Bioscientists. Washington: George Washington University Biological Sciences Communication Project Report No. 16-1964.